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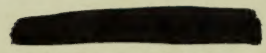

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TRANSACTIONS

OF

THE INSTITUTION

OF

MINING ENGINEERS.

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VOL. LXI.—1920-1921.

EDITED BY PERCY STRZELECKI.

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THE INSTITUTION OF MINING ENGINEERS.

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The Council of The Institution of Mining Engineers invite original communications on the subjects enumerated in the following list, together with other questions which are of interest to mining engineers.

Boiler explosions.
Bore-holes and prospecting, including methods of boring.
Brickmaking by machinery.
Brine-pumping.
Canals, inland navigation, and the canalization of rivers.
Coal-getting by machinery.
Coal-washing machinery.
Coke manufacture and the recovery of bye-products.
Colliery leases, and limited liability companies.
Compressed air as a motive power.
Corrosive action of mine water on pumps, etc.
Descriptions of coal-fields and other mineral deposits.
Distillation of oil-shales.
Duration of coal-fields of the world.
Electric mining lamps.
Electricity and its applications in mines.
Engine-counters and speed-recorders.
Explosions in mines.
Explosives used in mines.
Faults and veins.
Fuels and fluxes.
Gas-, oil-, and petroleum-engines.
Gas-producers and gaseous fuel and illuminants.
Geology and mineralogy.
Haulage in mines.
Industrial assurance.
Inspection of mines.
Laws of mining and other concessions.
Lead-smelting.
Light railways.
Lubricating value of grease and oils.
Lubrication of trams and tubs.
Maintenance of canals in mining districts.
Manufacture of fuel-briquettes.
Mechanical ventilation of mines, and efficiency of the various classes of ventilators.
Mining of mineral deposits.
Natural gas: its conveyance and uses.
Occurrence of mineral ores, etc.
Ore-sampling and sampling machines.
Petroleum-deposits.
Preservation of timber.
Prevention of overwinding and accidents in shafts.
Pumping machinery.
Quarries and methods of quarrying.
Rescue-work.
Rock-drills.
Safety-lamps.
Screening, sorting, and cleaning of coal.
Shipping and discharge of coal-cargoes.
Sinking, coffering, and tubbing of shafts.
Spontaneous ignition of coal and coal-seams.
Steam-condensation arrangements.
Steam-power plants.
Submarine coal-mining.
Subsidences caused by mining operations.
Surface-arrangements at mines.
Surveying and surveying instruments.
Transport on roads.
Tunnelling methods and appliances.
Underground conveyors.
Utilization of dust and refuse-coal.
Ventilation of coal-cargoes.
Water as a motive-power in mines.
Water-incrustations in boilers, pumps, etc.
Water-tube boilers.
Watering coal-dust.
Winding arrangements at mines.
Winning and working of mines at great depths.

The Council, if they think fit in any year, may award medals or other awards to the author or authors of papers published in the *Transactions*, or to persons who have distinguished themselves by their contribution to the advancement of mining and other branches of technology.

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TRANSACTIONS
OF
THE INSTITUTION
OF
MINING ENGINEERS.

THE SOUTH STAFFORDSHIRE AND WARWICKSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING,

HELD AT THE UNIVERSITY OF BIRMINGHAM, EDMUND STREET, BIRMINGHAM, FEBRUARY 21ST, 1921.

MR. J. R. FELTON, PRESIDENT, IN THE CHAIR.

DEATH OF MR. W. H. WHITEHOUSE.

The President proposed a vote of condolence and sympathy with the relatives of the late Mr. W. H. Whitehouse, a member of the Institute.

The vote was passed in silence, the members standing.

ELECTION OF MEMBERS.

The following gentlemen, having been approved by the Council, were elected :—

MEMBER—

Mr. ARTHUR WILLIAM GRAY, "Lyndhurst," Earls Road, Nuneaton.

ASSOCIATE MEMBER—

Mr. VICTOR PARRY, Croxdene, Bloxwich, Walsall.

STUDENTS—

Mr. LESLIE GILBERT PITT, Summerhill Court, Kingswinford, Dudley.

Mr. WILLIAM DENIS GANNON, 212, Showell Green Lane, Birmingham.

Mr. JOHN LEONARD WESTWOOD, Stork Hotel, Leicester Square, Walsall.

MEMOIR OF THE LATE ARTHUR SOPWITH.

BY ALEXANDER SMITH, M.INST.C.E.

By the death of Mr. Arthur Sopwith The Institution of Mining Engineers loses one of its most prominent members. He was one of the original founders of the Institution, and was elected President in 1893.

The late Sir George Elliot, Nicholas Wood, and John Daglish, when Presidents of the North of England Institute of Mining and Mechanical Engineers, each in his turn foreshadowed a federation of the several Mining Institutes in the different coal-mining districts, and the late Theophilus Wood Bunning, the Secretary of the North of England Institute, read a paper on the subject in August, 1887. No actual progress was made, however, until towards the end of that year, when negotiations were set on foot for federating the South Staffordshire and East Worcestershire Institute with The Institution of Mechanical Engineers. It was then that Mr. Sopwith urged the then Secretary (Mr. Alexander Smith) to communicate at once with Mr. Bunning, and press forward the other scheme which it was considered would be more appro-

priate and of greater advantage. This was done, and Mr. Sopwith and the Secretary attended the first meeting, held at The Institution of Civil Engineers, Great George Street, London, on June 6th, 1888, which was presided over by the late Sir Lothian Bell, Bart. As a result, the federation was launched on July 1st, 1888.

Mr. Sopwith was born at Newcastle-upon-Tyne, on September 21st, 1843, and was the second son of Mr. Thomas Sopwith, F.R.S., one of the most eminent engineers and geologists of his day.

At the age of 16 Mr. Sopwith began his mining apprenticeship at Towneley Colliery, County Durham, and later was articled at collieries in Northumberland. From 1864 to 1873 he filled various appointments abroad, and did some very useful and interesting work in Spain, where he opened out the coalfields in the Eastern Pyrenees, and also worked in the Bemez and other mining areas, later paying a visit to the lead-mines at Linares. He acted in an official capacity in India for a railway company, determining the question of contract with the Nerbudda Coal Company, making a survey of the locality, and reporting on various coal-outcrops in the Nerbudda valley and hills. In Bohemia he superintended the working of the brown-coal mines during 1871-1873, and had charge of mining where the seam was 60 feet thick—a task of no mean importance in those days. His work also carried him to Brazil in connexion with the St. John del Rey Mine.

In 1873 he was appointed manager of the Cannock Chase Collieries, and later became General Manager, which post he held up to 1919, and since then has acted as consulting director. Mr. Sopwith was one of the pioneers of electric-light installation in mines, and it was during the early days of his managership that this method of lighting was adopted at the Cannock Chase Collieries. This installation so impressed the scientific world that Mr. Sopwith was requested to read a paper on it at a meeting of the British Association, which he did, and for which he was highly congratulated.

Mr. Sopwith was a man of equable temperament, and never seemed perturbed. He was a good companion and staunch friend, and was always ready to do a good turn. To the many men under his control he was an ideal manager and friend, and he devoted a great part of his forty-six years connexion with the company in looking after their safety, welfare, and amusements. He and his family took the lead in and, in fact, mostly conducted all the religious, social, and philanthropical undertakings of the district in which he lived.

In the profession Mr. Sopwith held a high position; he was constantly consulted, and his opinions were much esteemed. In addition to being a member of this Institute, he was a member of The Institution of Civil Engineers, a Fellow of the Geological Society, a member of the North of England Institute of Mining and Mechanical Engineers, and a member of the South Staffordshire and Warwickshire Institute of Mining Engineers. In 1901-1904 he sat as a member of the Royal Commission on Coal Supplies, and, in conjunction with Prof. Lapworth, issued the report upon the resources of Staffordshire and Warwickshire. He was also an original member of the Imperial College of Science and Technology.

Mr. Sopwith took part in most of the important discussions of the Institute, and particularly of the South Staffordshire and Warwickshire Institute, and, owing to his large experience, his contributions have added much to the value of the *Transactions*.

Mr. Sopwith died suddenly on December 13th, 1920, passing away peacefully in his sleep.

NOTES ON GERMAN MINE-RESCUE APPARATUS.

By R. C. SMART.

Introduction.—The Germans in connexion with their military mining operations during the recent war in France had, like ourselves, to use mine-rescue apparatus. This was due to the enormous volumes of poisonous and inflammable gases produced by the detonation of large quantities of high explosives, and also to the porosity or permeable nature of the strata in which the galleries were driven.

The apparatus found, following an inspection of German mines captured in the April offensive of 1917 from the Arras sector up to Hill 70 in the Loos sector, were: (1) the Dræger 2-hour set; (2) the Dræger ½-hour set; (3) the Magirus ½-hour set; and (4) the Flottenatmer ½-hour set.

Nos. 1 and 2 were also found in German mines after the Somme offensive in 1916, and all were tested at the First Army Mine-rescue School. All were of the regenerative type, except the Magirus apparatus.

The 2-hour Dræger set showed no alteration or modification in design as compared with the Dræger 1912 apparatus in use prior to the war, and will not, therefore, be dealt with further.

Only a few of the large Dræger sets were in use by the enemy, the small ½-hour Dræger set being mainly employed. This was due to the fact that the large Dræger set was considered too heavy and bulky for use in mine galleries.

After the inspection of their galleries as to size, construction, etc., there is sufficient evidence in the majority of cases to justify the employment of the smaller apparatus. In one mine in particular near to Montreal Crater, in the Vimy Ridge sector, it would have been extremely difficult to negotiate the inclined drift or entrance to the mine with the large apparatus. The inclined drift reached a vertical depth of 83 feet in chalk, and was supported by timber frame sets 3 feet high by 2½ feet wide. At the bottom of the drift two galleries were set out Y fashion, and an air-trough 7 inches in diameter lying in one corner of the gallery carried the fresh air from the surface. The frame sets were made of 12 by 2½-inch timber with tenon and shoulder-joints, and each set was dropped a foot below the one preceding it, in order to gain depth as soon as possible for commencing the offensive galleries. This reduced the height of the drift to 2 feet, and must have handicapped the transport of men and materials considerably both during the stages of construction and afterwards whilst driving the galleries. In addition, when wearing apparatus in which the breathing-bag is worn low down on the front of the body considerable resistance to breathing is produced, due to the folding of the bag when bending in small galleries, etc.

As the three kinds of German apparatus described in the following pages are new in type, full details are given of their construction.

The Dræger Half-hour Apparatus.—The latest type found was that manufactured in September, 1916, and weighed 12 pounds when charged. It follows to a great extent the same design as the Salvus set, made by Messrs. Siebe, Gorman, & Company, Limited, London, except that it has not an automatic reducing-valve for the delivery of oxygen. A

noticeable feature in sets made about this date (September, 1916) was the absence of rubber in the constructional parts.

It will be seen from Fig. 1 that a positive circulation of air in the apparatus is given by means of the exhaling- and inhaling-valves O_2 and O_1 respectively, this being an improvement on the Salvus apparatus.

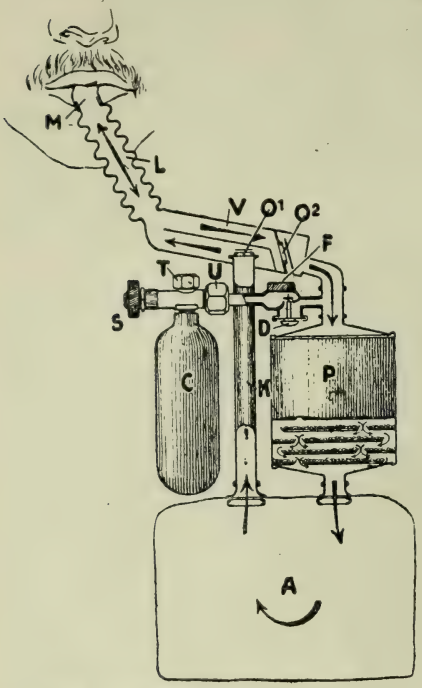

FIG. 1.—FLOW DIAGRAM OF DRÆGER ½-HOUR SET.

The exhaled air passes *via* the mouthpiece M, the tube L, and valve O_2 into the cartridge P (consisting of granular caustic potash and soda on trays) and thence into the breathing-bag A. From there it passes through the metal cooling-tube K (cooled by surface radiation) *via* the valve O_1 into the tube L. The oxygen in the cylinder C is at a pressure of 150 atmospheres, the main valve for the same, which is of the usual Dræger type, being at S. U is the main union for connecting the cylinder to the apparatus.

When the main valve S is opened, oxygen passes along the tube *via* the union U, past the pressure-gauge F, and into the circulatory system of the apparatus just above the cartridge P. An essential point is that oxygen is only admitted to the apparatus when the pressure-knob D is pressed —that is, the supply of oxygen is not automatic, but is controlled by the wearer as desired. If D is not pressed, no oxygen passes beyond the pressure-gauge F. It is thus of importance to wash all air, and therefore nitrogen, from the apparatus with pure oxygen before adjusting the mouthpiece. This point is emphasized in the manufacturer's instructions.

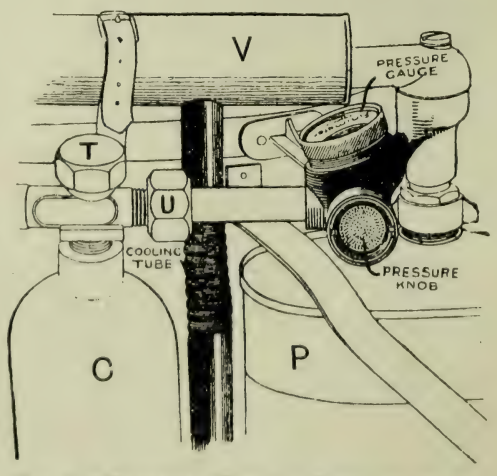

FIG. 2.—ENLARGED VIEW OF PRESSURE-GAUGE, PRESSURE-KNOB, AND COOLING-TUBE.

The apparatus in use is cool, but the weight-distribution is bad, and it possesses certain defects, due to the position of the breathing-bag, as previously mentioned, when traversing small mine galleries; also it is desirable to have an automatic delivery-valve controlling the supply of oxygen. The cylinder V acts to a certain extent as a saliva trap.

Fig. 2 is a larger view of the pressure-gauge, pressure-knob, and cooling-tube. *T* is a lock-nut for fastening the cylinder *C*.

Fig. 3 shows the apparatus in use, with an army gas-mask attached to the mouthpiece. The mouthpiece and wire nose-clip of ordinary design were usually used.

The makers claim 45 minutes as being the useful life of the apparatus when doing work; but after testing it from a practical point of view, it is more satisfactory to regard it as a half-hour set.

Fig. 3. — View of Dræger Apparatus in use, with Army Gas-mask attached to the Mouthpiece.

The Magirus Half-hour Apparatus.—The essential feature in this apparatus was the absence of any alkaline absorbent for removing the carbon dioxide in the exhaled air. The apparatus is fitted with a reducing-valve (*R. V.*, Fig. 4), and in the following test of the apparatus this was set to deliver 3 litres of oxygen per minute. An automatic relief-valve (*D*, Fig. 5), which opens on exhaling and closes on inhaling, prevents any uncomfortable rise of air-pressure in the apparatus. A main valve (*M. V.*, Fig. 5) of the Titan or Dræger type is used.

Fig. 4.—Magirus Apparatus.

The instructions for use are as follows:—

(1) See that the apparatus is undamaged before use.

(2) Test the amount of oxygen present in the cylinder *C*, as follows:—

150	atmospheres	= 165	litres	= 50	minutes	These times are for a man at work.
120	,,	= 130	,,	= 40	,,	
100	,,	= 110	,,	= 30	,,	
50	,,	= 55	,,	= 15	,,	

(3) Place the cylinder *C* on the back.

(4) See that there are no leakages, and tighten nuts.

(5) Put on mask (face), which must rest on, not under, the chin. Tighten the straps.

(6) The exhaling-valve *D* or relief-valve at the bottom of the air bag *A* must open on exhaling and close on inhaling.

FIG. 5.—BACK VIEW OF MAGIRUS APPARATUS, SHOWING THE BREATHING-BAG *A* AND THE VALVE *D*.

(7) Place the bag *A* over the head and rest it on the back.

(8) Attach the oxygen supply-pipe.

(9) Open the main valve on cylinder.

(10) If the eye-pieces become misty, clean them with a circular movement of the sockets.

(11) After the apparatus has been used, close the cylinder-valve or main valve tightly and replace it in the box.

The apparatus has not a positive system of air-circulation—that is, the wearer breathes directly into the breathing-bag, which is constantly fed with 3 litres of oxygen per minute.

In Fig. 5 the connexion between the bag and the cylinder at the bottom of the bag can be seen.

The following table contains details of an experiment carried out with a Magirus mine-rescue apparatus :—

Apparatus worn by Sergeant Lea, August 9th, 1916; age, 27; height, 5 feet 11 inches; weight, 168 pounds.

Weight of apparatus, 18 pounds (8·16 kilogrammes); pulse after 15 minutes, 86.

Period of wearing, 46 minutes.

Fall in pressure, 110 atmospheres; pulse after 1 hour, 78 (14 minutes after taking off the apparatus).

Reducing-valve set at 3 litres per minute.

Pressure.	Time.	Pulse.	Respiration.	Work done.
Atmospheres.				
115	7.23	80		
95	7.29			Walked 100 yards at 4½ miles per hour ; rested.
80	7.32			Walked 100 yards at 4½ miles per hour ; rested.
	7.36			Walked 100 yards at 4½ miles per hour.
	7.38	94		Climbed 15 feet up steps, then walked 100 yards on level.
70	7.41		26	100 yards walking at 3 miles per hour.
60	7.46			
55	7.51			100 yards walking at 2½ miles per hour.
50	7.55			Resting ; pain and discomfort around eyes and forehead.
40	8.0	88	28	Walking ; slackened down ; commenced to drag feet ; discomfort in breathing ; seemed to be very uneasy and staggered about.
25	8.4			
20	8.6	90		Walking, at rate of 3½ miles per hour, a distance of 80 yards.
5	8.9		30	Very heavy breathing.

In the foregoing experiment the wearer experienced great difficulty in breathing after the first period of walking 100 yards. The balance of the apparatus was good. The mask was a bad fit, and had to be tightened to such a degree to prevent access of air as to be distinctly painful. A slight headache was experienced after removing the apparatus, but it soon passed off. A serious defect in the apparatus is the position of the valve *D*; the respiratory-tubes passing over the shoulders are also too small in diameter. Means for the removal of carbon dioxide are required, and also better protection for the bag *A*. It will be noticed that a pressure-gauge is fitted to the apparatus.

The Flottenatmer Half-hour Apparatus.—This apparatus showed a marked advance in mechanical construction in German appliances of similar types. The respiratory tube was of sensible dimensions, the weight distribution was very good, and the apparatus was extremely cool to use; but it should be fitted with a reducing-valve. The makers state

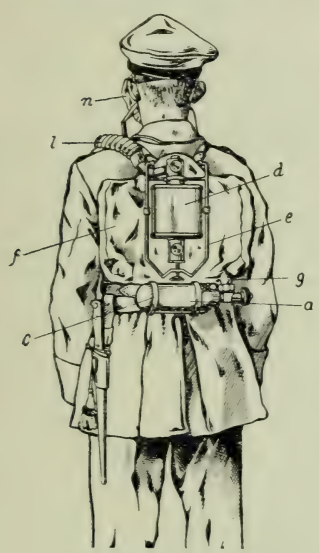

Fig. 6.—Back View of Flottenatmer K. 1916 (Model III.) Apparatus.

Fig. 7.—Side View of Flottenatmer Apparatus.

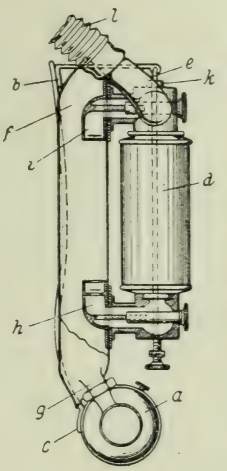

Fig. 8.—Section through Breathing-bag, Regenerator, and Respiratory valves.

that it is for use in irrespirable atmospheres or as a means of administering oxygen. The apparatus (Figs. 6, 7, and 8) consists of—

(1) A steel cylinder *a* for the oxygen, with a capacity of from 50 to 60 litres at a pressure of 120 to 150 atmospheres. The main valve is of the Titan type.

(2) A regenerator *d* (containing granular caustic potash) for carbon-dioxide absorption.

(3) A framework *e* carrying the apparatus.

(4) A breathing-bag *f*, fitted with bands *c* for carrying the oxygen-cylinder, and two connexions at the top and bottom respectively fitted with mica valves *i* and *h* (Fig. 8), the top one for inhaling and the bottom one for exhaling. A definite circulation of air is thus assured.

(5) A respiratory corrugated-rubbed tube *l*, fitted with a mouthpiece, nose-clip, and gas-proof mask *n* (Fig. 6).

(6) An automatic relief-valve *k* (Fig. 8) for relieving excess of air-pressure in the apparatus. (Note.—It would make for safety if this valve were not automatic.)

(7) A connexion *g* to the oxygen cylinder.

The weight of the apparatus when charged is 7·73 pounds (3½ kilograms).

Fig. 7 shows the method of carrying the respiratory tube over the shoulder, the mouthpiece (inside the mask), and the face-mask (made in two sizes).

A translation of the instructions for using the apparatus is as follows :—

(1) The minimum pressure at which the apparatus is to be used is 120 atmospheres.

(2) See that the regenerator shakes freely; one that does not do so is not to be used.

(3) Test the apparatus and connexions for air-tightness by filling the apparatus with oxygen before use and at short intervals.

(4) The supply of oxygen in the apparatus is controlled by the main valve; after filling the bag, the valve must be closed until the bag needs replenishing again.

(5) It is only used with the gas-mask in the presence of lachrymatory gas, etc., otherwise with usual nose-clip and mouthpiece.

(6) The exhaled air passes through the regenerator *via* the mica valve *h* (Fig. 8) into the breathing-bag; then *via* the mica valve *i* into the tube *L* for inspiration.

(7) The regenerator must be replaced at once after use, otherwise liquid potassium hydroxide enters the breathing-bag and damages it.

(8) Defective parts are to be replaced by a trained pioneer, otherwise fatal results may ensue. For well-known reasons rubber parts are not made from the best rubber, but from substitutes the life of which is doubtful.

The outstanding defects in this apparatus are :—

(1) Lack of adequate protection to the breathing-bag, in that it requires a stronger canvas cover.

(2) Absence of a pressure-gauge and reducing-valve.

The PRESIDENT (Mr. J. R. Felton) : Although the Germans have certainly taught this country a great deal, and probably we have still to learn much more from them, I think we are entitled to pride ourselves on the fact that they have not much to teach us in regard to rescue-apparatus. In the tests that have frequently been made on various types of appliances the English apparatus has come out on the whole more favourably than the German Dræger apparatus. I think that whilst the half-hour or short-time apparatus is of great interest, and doubtless proved of great usefulness during the war, I cannot see any great scope for its use in coal-mining operations.

Mr. S. L. THACKER (Walsall) : Was any structural improvement discovered in German apparatus found during operations in France? What was found to be the best method of administering oxygen to "gassed" patients or men suffering from carbon-monoxide poisoning?

Mr. R. C. SMART (Hednesford) : The two-hour Dræger set showed no advance on the 1912 design. The German method of administering oxygen to gassed patients or men suffering from carbon-monoxide poisoning was as follows :—A 50 or 100-cubic foot oxygen storage cylinder (at a pressure of 120-150 atmospheres), with a flat base, standing vertically,

and fitted with a main valve and a reducing-valve, was employed. A number of flexible metallic tubes were attached to face-masks fitted with pneumatic linings, and these were fastened to the storage cylinder, so that several persons could be given oxygen at the same time from the one cylinder. This method was good, and economical from the point of view of the oxygen supply, as valves were fitted in order to regulate the supply of oxygen to the individual tubes or masks. This question has been fully dealt with in my book entitled "Recent Practice in the Use of Self-contained Breathing-apparatus," 1921.

The further discussion of the paper was adjourned.

DISCUSSION OF MR. J. R. FELTON'S "NOTES ON AN EXPLOSION OF COAL-DUST AT PENNANT HILL COLLIERY, NEAR DUDLEY, WORCESTERSHIRE."*

Mr. J. R. Felton (Birmingham): Some of the questions raised in the discussion that followed the reading of the paper were answered at the time; but I promised to give at a later meeting analyses of the dust-samples and to reply to the other points raised.

In my view, the possibility of firedamp having played any part whatever in this explosion may be discarded. There was certainly nothing in the nature of faulty ground, nor any indication of a fissure or joint in the strata in the neighbourhood of the manhole where the shots were fired; moreover, there was a volume of 18,000 cubic feet of air passing along the road at a velocity of about 600 feet per minute. The deputy stated that he had made a careful examination for gas before the firing of each shot, but found no indication of its presence; in addition, I, along with officials of the mine, made several examinations shortly after the explosion, but with the same result.

Mr. William Charlton and Mr. H. W. Hughes both state that no other previous explosions in South Staffordshire have given rise to any suggestion of the participation of coal-dust; but I would remind them that even during quite recent years two accidents have occurred, namely, at No. 7 Netherton Colliery in 1911 and at Pennant Hill Colliery early in 1915, in both of which coal-dust almost certainly played an important part. In the former case ten men were burned (three of whom died), and most of these men were from 20 to 25 yards from the place where the shots were fired. The burning was, I think, due to the presence of coal-dust.

Although I do not regard the explosion now under consideration as an isolated case in South Staffordshire, I agree that it is fortunately an exceptional one, and, so far as I am aware, it affords one of the clearest cases on record, not only in South Staffordshire but also in this country generally, of the explosibility of coal-dust.

I cannot quite understand the statement of Mr. Hughes that "the Thick Coal acted as a neutral zone or incombustible-dust barrier." If by this is meant that on approaching the Thick Coal workings the percentage of incombustible dust increased and the dust became coarser, I agree; but that condition was due (1) to the haulage there being performed by horses instead of mechanically, as was the case out-bye, and (2) to the floor along the Thick Coal roads being of fireclay, thus

* *Trans. Inst. M. E.*, 1919-1920, vol. lviii., page 111.

producing incombustible dust, a fact to which I referred in the concluding paragraph of the paper. The dust from the Thick Coal Seam, in common with dust from other bituminous coals, is of ready inflammability, and Dr. Wheeler has found no difficulty in exploding it in tests carried out at Eskmeals.

Sir John Cadman asked for an analysis of the coal-dust, and Mr. C. H. Bailey wanted some information as to the fineness. These particulars I give below :—

Fineness.	Samples.			
	A1.	A2.	B1.	B2.
(*a*) Percentage of coal-dust passing through lamp-gauze	87·0	56·5	45·0	36·0
(*b*) Percentage passing through 240 × 240 mesh	65·0	26·0	16·0	13·5

Analysis of Coal-dust passing through Lamp-gauze.

	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	4·78	4·08	3·59	4·04
Volatile matter	19·27	26·84	23·42	21·40
Ash	38·04	35·64	30·93	43·69
Carbon dioxide from carbonates	2·50	1·90	0·35	1·00

Sample A1 was from the roof and sides at the manhole.
,, A2 ,, ,, floor ,, ,,
,, B1 ,, ,, roof and sides ,, landing.
,, B2 ,, ,, floor ,, ,,

It will be observed that the dust at the landing—which was about the point at which the explosion finished—was very much coarser than at the place where the explosion originated.

I agree with Mr. Sopwith that if a standard of 50 per cent. of incombustible dust be maintained, provided that it is of the requisite fineness, a condition is created that may be considered quite safe, and I think the experience gained at Eskmeals confirms this view.

Mr. S. L. Thacker (Walsall): The members are indebted to Mr. Felton for the trouble he has taken to supply the further detailed information asked for during the previous discussion; and in view of the very definite statements made by him, and in the absence of any further suggestions as to the cause of the explosion, I think we can now accept the conclusions arrived at in the paper.

Mr. Norman Forrest (Essington): It seems very remarkable that dust containing 38 per cent. of incombustible matter can become explosive. I think the point raised by Mr. Felton is that the question of fineness played the most important part; further, that it has been adequately proved by experience that, notwithstanding the quantity of ash, if the dust be sufficiently fine it is possible for it to propogate an explosion, and that this is what actually occurred at Pennant Hill Colliery.

Mr. D. E. Parry (Bloxwich): It does seem extraordinary that the explosion was caused by coal-dust. Apparently there was only 23 per cent. of volatile matter in the dust and 5 per cent. of moisture. All the evidence that was available at the enquiry went to show that the cause of the explosion was coal-dust, and as no gas was found before the shot was fired, we are bound to accept that view.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,

HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE, FEBRUARY 12TH, 1921.

LT.-COL. F. R. SIMPSON, PRESIDENT, IN THE CHAIR.

DEATH OF MR. ARTHUR SOPWITH AND MR. WALKER OSWALD TATE.

The PRESIDENT (Lt.-Col. F. R. Simpson): Before proceeding with the business of the meeting, it is my sad duty to allude to the death of Mr. Arthur Sopwith. Mr. Sopwith was elected a member of the Institute in 1863, and was President of The Institution of Mining Engineers for the year 1893-1894. He was a north-countryman, and the son of the late Mr. Thomas Sopwith, who, although not one of the original members, joined the Institute in 1853. Mr. Arthur Sopwith was well known to me and my family; he served part of his apprenticeship with my grandfather, and so has been a friend of my family for three generations. I was fortunate enough to hold my first appointment under him, and was with him for several years, and I know the respect in which he was rightly held as a mining engineer in the Cannock Chase district of Staffordshire. No one could have had a better friend, and I am sure the mining world will feel his loss. I propose that a letter of sympathy and condolence be sent to his relatives.

The resolution was unanimously carried, the members standing.

The PRESIDENT (Lt.-Col. F. R. Simpson): I have another sad duty to perform. I allude to the death of Mr. W. O. Tate, who was well known to all of us, and who was an active member of the Council for the past few years. We were all shocked to read of his death at the early age of 42; we feel that a useful career has been cut short, and I propose that a letter of sympathy and condolence be sent to his relatives.

The resolution was unanimously carried, the members standing.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated:—

HONORARY MEMBERS—

Prof. CHARLES JOHN HAWKES, Armstrong College, Newcastle-upon-Tyne.
Prof. GEORGE HICKLING, Armstrong College, Newcastle-upon-Tyne.

MEMBERS—

Mr. DONALD SIMPSON ANDERSON, Engineer, c/o Messrs. Haggie, Son, & Love, Limited, P.O. Box 899, Johannesburg, Transvaal.

Mr. ERNEST CHICKEN, Colliery Under-manager, Sea View, Horden, County Durham.

Mr. GEORGE JAMES GOODY, Mechanical Engineer, c/o The Paterson Engineering Company, Limited, Temple Chambers, Old Post Office Street, Calcutta, India.

Mr. CHRISTOPHER GREGORY HENDERSON, Colliery Under-manager, Shoreswood, Ashington, Northumberland.

Mr. WILLIAM HESLOP, Colliery Under-manager, Rose Cottage, Burnopfield, County Durham.

Mr. ROBERT HENRY HUSBAND, Colliery Manager, Lyndhurst, Holmside Avenue, Dunston, Gateshead, B.O.

Mr. GEORGE NATTRESS, Colliery Manager, Bentinck House, Pegswood, Morpeth.

Mr. JOHN THOMAS REED, Colliery Under-manager, 6, Ivy Terrace, South Moor, Stanley, County Durham.

Mr. GEORGE CARR REILLY, Salt Mine Manager, Greenholme, Carrickfergus, County Antrim, Ireland.

Mr. HENRY RICHARDSON, Colliery Under-manager, Clara Vale Colliery, Ryton, County Durham.

Mr. THOMAS LEE ROBINSON, Colliery Under-manager, Office House, Newton Cap Colliery, Bishop Auckland.

Mr. UPENDRA NATH ROY, Assistant Colliery Manager, Rewa State Collieries, Umaria, B.N.R., Central India.

Mr. JONATHAN SEVERS, Colliery Manager, Colliery House, Longframlington, Northumberland.

Mr. JOHN ARMSTRONG TEMPEST, Chief Electrician and Assistant Engineer, 15, Morrison Terrace, Mainsforth, Ferry Hill, County Durham.

Mr. PERCY FREDERICK THURLOW, Superintendent Engineer, Lobitos Oilfields, Limited, Lobitos, Paita, Piura, Peru, South America.

ASSOCIATE MEMBERS—

Mr. WILLIAM REGINALD ANDREWS, 4, Linden Terrace, Newcastle-upon-Tyne.

Mr. HUBERT ARTHUR BOOTH, Baluchistan Chrome Company, Limited, Hindubagh, Baluchistan, India.

Mr. GEORGE WOOD CLARK, Williamgill, Brampton Junction, Carlisle.

Mr. ARTHUR WEIGHELL, 31, The Avenue, Consett, County Durham.

ASSOCIATES—

Mr. FREDERICK EMMERSON, Back-overman, Elm House, Plessy Road, Blyth.

Mr. JOHN HUDSPETH, Coal Miner, 9, Simpson Terrace, Blucher Pit, Newburn, Northumberland.

Mr. ROBERT ERRINGTON ROBSON, Coal Miner, 2, School Bank, Walbottle, Newburn.

Mr. WILLIAM WANNOP, Mining Student, 70, Tavistock Road, Jesmond, Newcastle-upon-Tyne.

Mr. CHRISTOPHER WOOF, Coal Miner, Rowantree Hill, Brampton Junction, Carlisle.

STUDENT—

Mr. EDGAR SYDNEY GARDINER, Engineering Apprentice, Hoppyland House, Albert Hill, Bishop Auckland.

SUBSCRIBER—

THE ENGLISH ELECTRIC COMPANY, LIMITED, 64, Collingwood Buildings, Newcastle-upon-Tyne.

DISCUSSION OF MR. JOHN T. PRINGLE'S PAPER ON "THE PRODUCTION AND TRANSMISSION OF COMPRESSED AIR IN MINES."*

Mr. JOHN T. PRINGLE (Cramlington) wrote: Before replying to the comments of so many able members, I feel that some little explanation is necessary.

Prof. Louis has described the subject of the paper as important, and the measure of its importance can only be estimated when it is viewed broadly. To discuss the question of efficiency between this and any other power, or the failure of any isolated plant, will not help to achieve the object for which this paper was written. I know that at the present time engineers are still purchasing and putting down compressors. Compressor builders are fully employed, compressed-air machines are in demand, and are being snapped up on arrival in the Welsh ports. I am quite aware of the low efficiency of this form of power, of its cause, and of its probable solution. Further, that those who are prodigal in the use of compressed air are our own mining engineers in the Northern Inspectorate Division, for here more compressed air is used than in any other section of the British coalfields. In proof of this we need only examine the Home Office Report for 1919.

I have for the past twenty years studied very closely the relative applications of compressed air and electricity. During the last twelve years it has been my privilege to be engaged chiefly in the application of the latter form of power to probably every form of mining machine at present suitable to receive it. I am, and always have been, an advocate of electrical power, but when mining engineers have installed, and are still putting down, compressed-air installations, it is the duty of every engineer to see what can be done to improve its efficiency. This is the object of the paper, and the facts stated in the Home Office Report for 1919 suggested the subject to me.

In an air-compressing plant an attempt should be made to have something similar to that of an electric cable laid into the colliery, namely—an ever-ready and sufficient quantity of power at a fixed pressure to meet the necessary requirements.

Let us now examine the Home Office Report regarding the use of compressed air in the mines of the country, and in this (Northern) Inspection Division in particular.

Taking England, Scotland, and Wales, and comparing the years 1919 and 1918, it will be found that thirty-four additional collieries had adopted coal-cutting machines and that 441 more coal-cutters were installed in 1919. Of these only 153 were driven by electricity, whilst 288 were driven by compressed air. Therefore, of the total number of additional machines installed, the mining engineers of this country have evidently chosen 88 per cent. more compressed air than electrical machines.

In the Northern Division alone, which had the greatest number in 1919, there were installed in this area a total of 1,025 machines. Of these only 171 were driven by electricity, whilst 854 were driven by compressed air. Consequently no less than 399 per cent. more compressed air than electrical machines were installed.

There were throughout the British Isles 4,482 machines, and more than 49 per cent. of these are working in the two northern areas. Of

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 146.

this number 1,950 are electrically driven, and 2,532 are worked by compressed air; or of the total number installed, there are 29·8 per cent. more driven by compressed air than by electricity. Surely this is sufficient reason why we should examine very minutely the details of the loss of efficiency in this form of power.

Mr. Mark Halliday states that I have not said much of compressed air that is new. The defects in compressed air will not, however, be eliminated by something new regarding it, because any new invention would have to rely upon the basic principles of this form of power. These principles are as old as the power itself; and as they are so defective, I feel sure that anything new cannot be a success until the fundamental factors are dealt with successfully. With regard to isothermal power and overall efficiency, the isothermal power is the net power in the air available at the receiver; and on looking over a few tests, I think it can be taken as fairly accurate that the efficiency of compression from atmosphere to receiver is, at its greatest, 70 per cent.; in other words, the energy of the air in the receiver is 30 per cent. less than the heat energy expended in the engine.

The *transmission* loss in power by pressure is accompanied by a proportionate increase in volume, and some compensation is produced; but there is no loss in actual volume of free air. In well-designed mains the loss of pressure is small, and the actual loss of power still smaller. The principal loss is in leakage, which ought not to occur if the system is properly attended to. In order to obtain perfect transmission of compressed air, a pipe of increasing diameter should be installed. Many engineers have overlooked this point, and put in pipe-lines the dimensions of which are based upon the theory that if a certain head is required for 1,000 feet of pipe, twice as much is necessary for 2,000 feet. This theory is not correct for air service, because the head is lost after the first 1,000 feet, and this head is changed into volume for the second 1,000 feet, and so on. However, if the lines are put in to give a flow of from 20 to 25 feet per second, for an initial pressure of 100 pounds there will be a loss of only 3 per cent. per mile. As this figure can be taken as the power loss also (although it is less than this), and assuming the efficiency of the air motor to be 85 per cent., we have:—

	Per cent.
Loss at compressor	30
,, in transmission	3
,, at motor	15
Total loss	48

It will therefore be seen that the overall efficiency in a well-designed system would be about 52 per cent.

If it were possible to install a heater and reheat the air, its efficiency could be raised 25 per cent., which would bring the overall efficiency up to 77 per cent., and that would be within acceptable limits.

I agree with Mr. Halliday that a 30 to 35-horsepower electric motor is sufficient to drive a longwall coal-cutter, but I am inclined to differ from him when he states that a compressor of 700 cubic feet capacity compressing to 80 pounds per square inch is necessary to drive a similar coal-cutter. I think this figure is on the high side, and it has been proved in practice that a machine of 500 cubic feet will do the work efficiently.

A coal-cutter of this kind generally has two cylinders, 8½ and 10 inches

in diameter respectively, and will run at 150 revolutions per minute. Taking the cut-off at half-stroke, 49 cubic feet of air will be consumed per minute, and as it is compressed to six atmospheres, this will require a compressor of, say, 300 cubic feet capacity. Allowing 15 per cent. as losses for adiabatic compression, it will take 0·183 horsepower to compress 1 cubic foot of air at a temperature of 60° Fahr. up to 80 pounds gauge pressure. It will, therefore, take ($0{\cdot}183 \times 300 =$) 54·9 horsepower as against 35 electrically. This is ($140 - 55 =$) 85 horsepower less than Mr. Halliday stated was required—these being the theoretical figures.

As a firm practical figure, I will take F. C. Weber's table. In order to cut off in a motor-engine at two-thirds stroke, 13·75 cubic feet of free air per minute, compressed to a gauge pressure of 80 pounds per square inch, will be required. Taking the coal-cutter horsepower at 34, we get $13{\cdot}75 \times 34 = 467{\cdot}5$ cubic feet of free air as the capacity of the compressor. This is 233 feet less than the quantity given by Mr. Halliday. The actual brake-horsepower necessary to compress 467·5 cubic feet of free air $= 467{\cdot}5 \times 0{\cdot}183 = 85{\cdot}5$ horsepower. Therefore, the efficiency between an electric drive and compressed air is actually 2·4 :1, and not 4 :1 as stated by him.

With respect to bad pipe-lines, those responsible for the design and upkeep are entirely to blame. Bad pipe-lines are not present in well-designed plants.

I agree with Mr. Halliday that one of the reasons for the inefficiency of compressed air as a power-transmitter is the temperature acquired by the air during compression; but I differ somewhat from him when he asserts that the heat of compression makes it impossible to utilize the expansive properties of the air in the motor without freezing at the exhaust. When freezing occurs, the first recourse that comes into one's mind is to reheat the air; but, in order to solve this difficulty, one ought to be successful if the opposite to this is done, and the line is drained.

I will first consider the cause of freezing, and after that its prevention can be dealt with. The air never freezes, but the deposition of moisture on the surface of the pipes or passages freezes, and these areas become reduced. There are hundreds of machines—locomotives, rock-drills, pumps, and hoists—that run and are guaranteed to run without freezing where no reheating is employed.

Two factors produce freezing—free moisture and low temperature. One without the other can do no harm. The capacity for moisture is determined by the combined conditions of pressure and temperature to which it is subjected. In compression the increase in temperature of the air acting at the same time as the decrease in volume seems to keep pace with the tendency to drop moisture; hence we get no water in the compressor. As the air cools, the water begins to be released, as the humidity of the atmosphere regulates the quantity of water deposited.

When an air-motor freezes, we imagine that the water is precipitated by the air at the moment that freezing occurs. This is not so, for the water is deposited in the pipes before it reaches the motor, and is carried as entrained water by the friction of the air. The lowering of the air-temperature by expansion causes this water to freeze.

Receivers placed near the compressor do not always remove the water, because of the rapid movement of the air uncooled through them into the pipes. Here it finally cools, and deposits the moisture, which later gives the trouble by freezing.

Jet-compressors were once used for the purpose of cooling the air, and they are looked upon yet by some users of compressed air as capable

of giving dryer air, which is less liable to freeze than the air from the present dry compressor.

In order to get rid of all trouble from water in the air, care should be taken that when the air passes a point where it is still at full pressure, and has reached its lowest temperature, such means of drainage shall be provided that none of the liberated water shall be carried into the pipes. This can be accomplished by several forms of drainers or traps. One of special construction, the "flint trap," is very good for this purpose. The air passes through three chambers filled with flint-chips, which assist in taking out the moisture. If an after-cooler is installed, freezing will be entirely eliminated.

As pressure has an important bearing upon this question, short transmissions at low pressures are more likely to be accompanied by freezing than long transmissions at high pressure. The latter allow the air to cool, and more drainers can be fitted. Further, high-pressure air is of less volume than low-pressure air, and has less water in suspension; in addition, it is practically immune from freezing.

Taking, for instance, air at a gauge pressure of 1,000 pounds per square inch, for a long transmission smaller pipes and receivers will be required for the same power conveyed or stored. If this air is cooled and drained and expanded to 100 pounds per square inch, and allowed to regain its normal temperature, it will be found, when it has expanded to more than eight times its normal volume, that it can be saturated only one-eighth, and that no water can be deposited by it in expanding from 100 pounds per square inch; no matter how low its temperature, there can be no freezing.

Another good method is to increase the pressure of the air, cool it, then transmit it, put in two receivers 300 feet apart, and insert a reducing-valve before it reaches the first receiver; then wiredraw it so as to reduce its pressure. This will deposit half the entrained water in the first receiver, and this must be tapped off. The temperatures lost by the reduction in the pressure will be regained before it reaches the machine (1,000 cubic feet of air contains 1 pound of water).

Another form of freezing, due to the atmosphere, is eliminated by covering the pipes.

With regard to reheating, this has been fully dealt with in the revised paper as printed in the *Transactions*. I should say reheat whenever you can, but not above 400° Fahr., or lubrication troubles will ensue. It can be taken that the cost of reheating is less than an eighth of the cost of the same volumes produced by compression, and the efficiency of the system could be raised by 25 or 35 per cent.

If the air can be reheated to 100° Fahr. underground, it would result in a saving in power. Assuming 400 cubic feet for each heater. A coke or steam reheater would do for the surface, and I have seen these used underground; the former takes 1·3 pounds of coke per horsepower added, and this is much more efficient than that of the best engine and boiler practice.

For underground work there is not much choice, and it lies with electric reheaters and coke reheaters. It is better perhaps to rule the latter out. For portable machines, reheaters are, economically, out of the question. An electrical reheater is probably the only practical apparatus to use underground. This can be in the form of an inner chamber, fitted with grid resistance, and enclosed in an enlarged air-chamber slightly larger than the pipe. The grid would take a heavy current at low voltage—say, 120 amperes at 5 volts—and be fed through

a single-phase transformer from the 600-volt mains, or otherwise. At a low voltage the protecting insulation need not be expensive to ensure safety. I think that a safe reheater would be one similar to that employed on underground locomotives, the mine air being driven through the reheater tubes by the ejector action of the exhaust.

A further point raised was the measurement of air-flow. It is quite an easy matter now to measure the air-flow, and Prof. Louis has mentioned one type of meter for doing this. I have had some experience with the General Electric Company's flow-meters. If the cone and nozzle be put in the service-pipe at the correct place, and the installation carried out according to the maker's directions, a successful record of the air passing, indicated by pen and pointer, will be obtained. There are several types of instruments, and their calibration varies.

Prof. Louis has raised the important and interesting question of the Taylor compressor. He is undoubtedly correct when he states that it is not well known in this country. It has, fortunately, not escaped my notice, but I did not include it for the following reasons :—

(1) I did not think that it would be applicable to most of the collieries in this coalfield, owing to there not being a sufficient volume of water available, and that from a natural source.

(2) I had not had any practical experience with the Taylor compressor.

The following remarks, however, may be of interest. The Taylor compressor was invented in 1878, and first put into operation by Mr. J. P. Frizell, of Boston, U.S.A. An account of it is given in the *Journal of the Franklin Institute*, Vol. XC., page 145, and an abstract of Mr. Frizell's paper appears in the *Minutes of Proceedings of the Institution of Civil Engineers*, 1880-1881, Vol. LXIII., page 347.* This compressor consists of a vertical compressing pipe, through which water is allowed to fall. This pipe is fitted with a suitable head-piece to admit jets of air, which are drawn in by the falling water. These mix with the water, which breaks into foam; through this the bubbles tend to rise and escape. After the water and air have fallen the depth assigned to them (which is the water-head necessary to produce the compression desired), the direction of flow is then changed to the horizontal by a deflector, and the volume of water and air is diminished. The compressed-air bubbles are liberated, and are collected in a suitable chamber. As the pressure in this chamber corresponds to the effective head of water—that is, its depth below the level of the outflow—no pistons, valves, or moving parts are required. This is a highly-desirable form of compressor, and its efficiency is higher than any yet attained; moreover it gives perfectly dry air.

Huge plants on this principle have been installed, and one described by Mr. D. E. Woodbridge in *The Engineering and Mining Journal* of January, 1907, Vol. LXXXIII., page 125, is worthy of mention.† The compressing pipes were 5 feet in diameter, lined with concrete, and 340 feet deep, with a terminal head of 72 feet. The air was admitted at the top by 1,800 $\frac{3}{8}$-inch diameter feed-pipes, and three complete units were installed. The receiving chamber at the bottom was 281 feet long, and 18 by 21 feet in cross-section, whilst the air was drawn off by a 24-inch main, the air-space being 80,000 cubic feet and the remaining space water. At the end of the chamber is an inclined shaft 270 feet in

* "On the Compression of Air by the Direct Action of Water."

† "The Hydraulic Compressed-air Power Plant at the Victoria Mine."

vertical depth, through which the water returns to the surface. The air has a pressure-head of 270 feet, or 118 pounds per square inch.

When the three units are in operation, with a total capacity of from 34,000 to 36,000 cubic feet of free air per minute, about 70,000 cubic feet of air per minute can be drawn off for a period of 18 minutes with not more than a 5-pound drop in pressure. Prof. F. W. Sperr gave the following results on test :—

Air Measurements.

Square feet.	Velocity, in feet per second.	Cubic feet, per minute.	Absolute pressure.		Horsepower.
			Free air.	Compressed air.	
4	49·74	11,930	14	128	1,623

Water Measurements.

Flume area, in square feet.	Velocity, in feet per second.	Cubic feet, per minute.	Head, in feet.	Horsepower.	Efficiency. Per cent.
67·03	3,684	14,820	70·0	1,961	82·2

Over 4,000 horsepower can be developed by the three units, and the total cost per horsepower per year was 8s. 4d.

Another point raised by Prof. Louis is in regard to stage-compression. My paper, as first printed, differs from my notes, as it omitted the completion of a sentence which should have read " in every case above 65 pounds per square inch." In testing different plants I have found a marked improvement in results from stage-compressors from this pressure upwards.

I agree that the point of change from one to the other lies between 60 and 100 pounds per square inch, and I think that this point is at least between 65 and 70 pounds. The only additional capital outlay necessary would be the intercooler, and for compressors below a pressure of 100 pounds per square inch this would not be excessive. It must, of course, be covered by the power saved.

I agree with Prof. Louis that it is preferable at times, in connexion with turbo-compressors, to put in mixed-flow turbines to drive compressors, and to utilize the existing exhaust-steam in a similar way as was pointed out in Mr. Kirkup's paper on " Steam Economy."* Failing this, where the boilers are almost worn out an electrically-driven compressor would be the next best thing. I agree that for high capacity turbo-compressors are highly desirable and efficient, but there appears to be a difficulty in running them in parallel into the same main.

The underground receiver described by Prof. Louis has been ever present in my mind since he introduced it to me as a student some fifteen years ago. I have never seen one, but its usefulness cannot be questioned, and it would be helpful in keeping the pressure up. It is not quite the type I should desire, because it would need to be of considerable dimensions, and would not be quite as flexible as a hydrostatic appliance. My aim is to keep the pressure constant, no matter what the demand may be.

Another way of doing this would be to have underground compressors. These are desirable in many respects, more especially on account of their

* *Trans. Inst. M.E.*, 1920-1921, vol. lx., page 17.

efficiency, through being close to the face. This would eliminate defects in the pipe-line. These are, however, high-speed machines—in most cases inaccessible, sadly neglected, and depending upon the hot dust-charged mine air for their feed. It is also at times difficult to get a good clean supply of cooling-water, and as a rule mine water soon causes a heavy deposit in the jackets. The fact that several eminent mining engineers have tried them, and have abandoned their use in preference to surface-compressors, is proof that they are seriously defective.

With regard to Col. Blackett's remarks, I can only conclude that his experience with compressed air has been a complete failure to develop a working installation with average economy. As compressed air was only introduced as a power in 1849, it was not used to any extent in mines until about 1862. Col. Blackett was introduced to it in 1880, and used it until 1890. This period was a transitional one, for wet compressors were being replaced by dry machines; and as I have had some experience with one or two machines of this period, the wonder to me was that they could contain air, much less compress it.

The science of pneumatics and the thermo-dynamics of heat-engines were not understood then as they are now. At most collieries an engine-indicator was rarely to be found, and, if found, was seldom applied. I cannot conceive any engineer to be in anything but a helpless condition when investigating the defects of this power without an indicator, and a thorough knowledge of diagram analyses.

Col. Blackett mentioned leaky pipe-lines due to the working of the pit. This was not recorded in the reporter's notes, but I took it down as an important point. At this period the pipe-lines would be constructed mostly of metal, with flanged joints—a very unsatisfactory arrangement for a pit-main. New and more flexible pipes and joints have come into use since that period, and leaky joints are almost unknown in modern systems. After all, leaky joints and small pipes in place of large ones are not the fault of the power, but of the engineers responsible for the maintenance and design of the system.

When one takes into consideration a system of power such as the Taylor compressor described in my reply to Prof. Louis, and also a system such as is in use to-day in Paris, where there is a compressed-air installation with 140 miles of pipes, and air is transmitted at a pressure of 75 pounds per square inch, with a loss of only 18 per cent. at the farthest end, one is inclined to think that the possessor of the misguided mind is certainly not the inventor of this form of power, but the engineer who does not use it to advantage.

I do not agree that all the improvements we hear of to-day, excepting stage-compressors, were thoroughly practised thirty to forty years ago. Col. Blackett could not possibly then have prevented freezing by a reducing-valve method, because this form of valve was invented after that date. Furthermore, he did not install, but only thought of installing, an underground receiver similar to that described by Prof. Louis, which would doubtless have improved the system.

With respect to lubrication, it was stated that after many experiments soap and water in the form of a spray at each stroke was the best. This is entirely useless as a lubricant, and if used continually, I am afraid that very soon a new compressor would be needed. It is a good cleanser, but has long been discarded by modern engineers as a lubricant. The spray injection would be the cause of all the good obtained—not as a lubricant, but by cooling the air during compression. If the air in the compressing system did not give more than a quarter of the efficiency of

the electrical system, it must have been a bad system, and in consequence required investigation.

The latter part of Col. Blackett's remarks regarding surface and underground compressors have been dealt with in my reply to Prof. Louis.

I agree with Mr. Leach that the noise of the exhaust from compressed-air machines is objectionable, more especially when movements of the roof take place, and when tubs are in motion on the haulage-roads. Electric coal-cutters are remarkably silent, but a long step forward has been made in this direction by the introduction of the "Turbinair" cutter, which I think in time will entirely scrap those of the reciprocating type. I have made enquiries from different coal-cutter makers, and it is remarkable that none of them has ever had a serious objection raised in regard to this point.

With the exception of coal-cutters the gearing of which is entirely encased, I think it will be found that most electrical machines employed in mines are not exempt from this disturbing factor, and it should be considered with regard to them also. It is to be borne in mind that an electric motor is a high-speed machine, and most mining tools or engines operate at a low speed. Unless it is an objectionable worm-drive, there is considerable noise in the necessary gearing employed to reduce the speed, even when the gear is machine-cut and with double helical or staggered teeth. The elimination of noise from a compressed-air machine should be easily accomplished by any practical engineer, who with dry air would adopt a silencer similar to that employed on a motor-car.

The President (Lt.-Col. F. R. Simpson) has stated that we would not use compressed air if we could help it; with this we all agree, although the field appears wide enough for both forms of power. Electricity is certainly gradually superceding compressed air for haulages, pumping, and longwall coal-cutting generally, but not for heading-machines and other auxiliaries, both below ground and on the surface. Electricity will probably eliminate within the next thirty years the whole of the existing steam-plants in this section of the coal-bearing area. There are, however, certain cases at the present time in which electricity would be outruled, but the present unfavourable conditions will alter in its favour as time goes on.

With regard to the shortening of pipe-lines, this is a simple matter if underground compressors are installed. These have already been dealt with. With mains of ample size, leakage is the only loss that may give concern; but this will be eliminated if the right type of pipe is put in and followed up as the workings extend. If this detail is attended to in the same way as we are compelled to attend to the cross-section and leakage on our electrical cables, it will be found that a marked improvement in the productivity of compressed-air transmission will ensue.

The mining world is waiting for that which the President has stated, namely, an "electrically-driven percussive machine." I think the nearest attempt to this is the Temple-Ingersoll electric air-drill, which is a 6-horsepower machine without exhaust. An invention of this kind will, in my opinion, not lie along the lines of magnetic attraction and repulsion, as has been attempted by several investigators, but by a magnetic rotary motion transformed to a reciprocating one by sonic transmission through an air or water medium. I think that within the next few years the desire for a machine of this type will be realized.

The further discussion of the paper was adjourned.

APPLICATION OF CEMENTATION TO MINING.

Major H. Standish Ball delivered a lecture on this subject, which was illustrated by a large number of lantern-slides.

Mr. C. C. Leach (Seghill): Can any kind of rock be cemented? Would your process obviate the necessity of lining shafts in view of the suggestion that shafts should now be bricked from top to bottom. If they are cemented, why should they be bricked?

Mr. Philip Kirkup (Low Fell): With regard to the consistency of the cement, is it, to use a homely phrase, in the character of pea-soup or of porridge? Then as to its purity, does it consist of a mixture of sand and cement in the proportion of 2 to 1, 3 to 1, or 4 to 1?

Mr. John English (Heworth): Does any deterioration take place after a number of years?

Mr. Mark Ford (Washington): What are the advantages of holes of different diameters? At one place I was at 6-inch holes were employed, whilst at Thorne, they are, I believe, boring 1-inch holes.

Major H. Standish Ball (Doncaster): Cementation can be applied to practically any sort of rock. Among the many types successfully treated may be mentioned the Rand Banket of South Africa, the New Red Sandstone of Yorkshire, the Blue Pennant Rock of South Wales, and the Limestone of France. The one case in which it cannot be used is "running sand." The process does not obviate the necessity of lining shafts, for, though it seals off the fissures, there still remains the risk of falls of ground. The practice is, therefore, generally to put in concrete lining after the water has been partly, or completely, shut off, according to the class of ground.

Mr. Leach: Can you cement clay-rocks?

Major Ball: Yes. With reference to the consistency of the cement, the percentage varies at the commencement of injection, about a $2\frac{1}{2}$-per-cent. pulp being used, the percentage of cement gradually increasing as the injection approaches completion. A special finely-ground cement with no impurities is made for purposes of injection. With regard to the question of the possibility of deterioration of the work, there is no record of such having occurred, nor is it in the slightest degree likely. As to the size of the holes for injection, the probability is that the 6-inch diameter holes mentioned by Mr. Mark Ford were "freezing holes," and not cementation holes. The usual practise is to have holes of about $1\frac{1}{2}$ inches in diameter.

Mr. Herbert Flesher (Hebburn): I take it that one of the chief objects of cementation in shafts is to do away with any residual water when the sinking is completed? What is the relative speed of putting down shafts by cementation compared with pumping?

Major Ball: It is a somewhat difficult matter to make such a comparison, as so many factors are involved. Taking everything into account, sinking by cementation is slightly faster, while the saving in pumping costs is most apparent. The most difficult type of sinking so far encountered is in the New Red Sandstone, where an overall speed of 12 feet a week is an average figure. In any other type of rock, sinking is considerably faster.

The "P.P." Safety Shot-firing Appliance was exhibited, described, and demonstrated by Mr. T. A. Parry, of Messrs. Price, Pryse, & Company, Limited.*

A new Safety Detonating Appliance was exhibited, described, and demonstrated by Mr. W. L. Rowe.

MEAN MAGNETIC DECLINATION FOR EACH TWO HOUR INTERVAL FROM JANUARY 30TH TO FEBRUARY 26TH, 1921, AS RECORDED AT KEW OBSEKVATORY, RICHMOND

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
	Jan.		14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	30	0	24′·5	25′·0	24′·0	24′·0	24′·5	27′·0	27′·5	25′·5	25′·0	24′·0	22′·5	21′·0	24′·5
Mon. ..	31	1	22·5	24·5	24·5	24·0	24·5	27·5	29·0	28·0	25·5	23·5	24·0	24·0	25·0
	Feb.														
Tues. ..	1	1	24·5	25·0	25·0	24·0	25·0	26·5	27·0	27·5	26·0	20·0	22·5	24·0	25·0
Wed. ..	2	1	24·5	24·5	24·5	25·0	25·5	26·5	28·5	28·5	25·5	22·0	24·5	23·5	25·5
Thur. ..	3	0	24·0	24·0	22·5	23·5	24·0	26·0	26·5	25·5	25·0	24·5	24·0	23·5	24·5
Fri. ..	4	0	24·5	24·5	24·5	24·0	24·0	26·0	26·5	26·5	26·0	25·5	24·5	23·5	25·0
Sat. ..	5	1	23·0	23·5	23·5	23·5	24·0	27·0	30·5	30·0	28·5	25·0	21·0	21·0	25·0
Sun. ..	6	1	19·5	26·5	24·5	24·0	24·0	25·0	26·0	27·0	24·5	23·5	23·0	23·0	24·0
Mon. ..	7	0	24·0	24·0	24·0	23·5	23·0	24·5	27·0	27·0	24·0	22·5	23·0	23·5	24·0
Tues. ..	8	0	24·5	24·5	24·0	24·0	24·0	26·5	28·5	27·0	24·5	23·5	23·0	23·0	25·0
Wed. ..	9	0	24·0	24·0	23·5	23·0	22·5	24·0	26·0	26·0	25·0	23·5	23·5	23·5	24·0
Thur. ..	10	0	24·0	24·0	24·0	23·5	23·5	25·5	27·5	27·5	25·5	24·5	23·5	22·5	24·5
Fri. ..	11	0	22·0	23·0	23·5	24·0	23·0	24·0	26·0	26·0	25·0	24·0	23·5	23·0	24·0
Sat. ..	12	0	24·0	24·0	24·0	23·5	23·0	25·5	26·5	25·0	25·0	24·0	23·5	23·5	24·5
Sun. ..	13	1	24·0	24·0	24·0	23·5	23·5	25·0	27·5	28·0	27·0	25·5	22·0	20·5	24·5
Mon. ..	14	1	21·0	20·0	21·0	23·5	24·0	25·0	27·0	26·0	24·5	24·0	23·0	21·0	23·5
Tues. ..	15	1	20·0	22·0	22·5	23·5	25·0	27·0	28·0	26·5	25·5	24·5	24·0	23·5	24·5
Wed. ..	16	0	24·0	24·0	23·5	23·5	24·0	26·0	27·5	26·0	24·5	24·0	24·0	24·0	24·5
Thur. ..	17	1	23·0	21·0	18·5	21·5	23·5	24·5	28·0	27·0	25·5	25·0	24·0	24·0	24·0
Fri. ..	18	0	24·0	24·5	24·0	23·5	23·5	25·5	27·5	26·5	24·5	23·5	24·0	24·0	24·5
Sat. ..	19	1	23·0	21·5	23·0	23·5	23·5	26·0	29·5	27·0	25·5	24·0	23·5	23·5	24·5
Sun. ..	20	0	23·0	22·5	23·0	23·0	23·5	24·5	26·0	26·0	24·5	24·0	23·0	22·0	24·0
Mon. ..	21	1	19·0	22·0	25·0	25·5	24·0	25·5	28·0	26·5	24·5	23·0	23·0	23·5	24·0
Tues. ..	22	0	23·5	23·5	24·0	22·5	22·5	24·5	27·0	26·5	24·5	24·0	22·0	22·5	24·0
Wed. ..	23	0	24·0	24·0	24·0	23·0	21·5	23·5	26·5	26·0	24·0	23·5	23·5	23·5	24·0
Thur. ..	24	0	23·5	23·5	23·5	22·5	20·5	24·0	26·5	25·5	24·5	24·0	23·5	21·5	23·5
Fri. ..	25	0	22·0	24·0	23·5	22·5	21·0	24·5	29·0	27·0	24·5	23·0	21·0	23·0	24·0
Sat. ..	26	1	23·5	23·5	23·5	22·5	21·5	24·5	27·0	25·5	24·0	22·0	23·0	23·5	23·5

Diurnal Inequality (*i.e., departure from mean value for day*).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
February, 1920	−1′·8	−1′·2	−0′·9	−0′·7	−0′·9	−1′·2	−1′·5	−2′·2	−2′·7	−1′·7	+1′·7	+3′·0
January, 1921	−0·9	0·5	−0·6	−0·3	−0·5	−0·6	−0·6	−0·5	+0·1	+1·1	+1·9	+2·9
January, 1920	−1·2	−0·6	−0·2	−0·1	−0·5	−0·7	−0·9	−1·4	−1·7	−0·6	+1·2	+2·7

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
February, 1920	+4′·5	+4′·8	+4′·2	+2′·8	+1′·8	+1′·3	+0′·6	−0′·7	−1′·4	−2′·0	−2′·4	−2′·6
January, 1921	+3·0	+2·3	+1·5	+1·1	+0·8	−0·1	−1·1	−1·7	−1·8	−2·1	−2·0	−1·4
January, 1920	+4·1	+3·7	+2·9	+2·0	+1·2	+1·0	+0·2	−1·1	−2·6	−3·0	−2·5	−2·1

Erratum: Mean value for August, 1920, should be 14° 29′·3, not 14° 27′·4.

Mean Value for Month.

February, 1920.	January, 1921.	January, 1920.
14° 35′·1.	14° 25′·8.	14° 35′·8.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.
Character "0" means a day wholly free from any but small disturbances.
" "1" " " part or all of which is moderately or considerably disturbed.
" "2" " " part or all of which is highly disturbed.
The above values were obtained from measurements made after "smoothing" the curves.

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* For description, see "The Prevention of Misfires and of Accidents in Blasting Operations," by J. S. King, B.Sc., *Trans. Inst. M. E.*, 1912-1913, vol. xlv., page 2.

THE MINING INSTITUTE OF SCOTLAND.

GENERAL MEETING,
HELD AT THE HERIOT-WATT COLLEGE, EDINBURGH, FEBRUARY 5TH, 1921.

MR. ROBERT McLAREN, M.P., PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated by the Council, were declared elected :—

MEMBER—

Mr. FRANK WOOLLASTON TIMMIS, Civil and Mining Engineer, Las Minas de Rio Tinto, Provincia de Huelva, Spain.

ASSOCIATE MEMBERS—

Mr. PERCY GEORGE DOMINY, Mining Engineer, 39, King's Park Road, Cathcart, Glasgow.

Mr. THEODORE JAMES HUGHES, Mining Engineer, 60, Polwarth Gardens, Hyndland, Glasgow.

Mr. JAMES ALEXANDER THORNE, Manager in Scotland for the Ingersoll-Rand Company, 20, Renfrew Street, Glasgow.

ASSOCIATES—

Mr. JAMES SAMUEL CARSON, Mining Student, Saughs, Newton Grange, Midlothian.

Mr. JAMES MITCHELL COWAN, Mining Student, Wellsgreen Cottages, by Windygates, Fife.

Mr. WILFRID H. S. LAWSON, Mining Student, 6, Hailes Street, Edinburgh.

Mr. ANDREW ARTHUR DIACK MITCHELL, Mining Student, 61, Duke Street, Glasgow.

Mr. FRANCIS JOHN CAMPBELL MOFFAT, Mining Student, 1, St. Bernard's Crescent, Edinburgh.

Mr. JAMES NORVAL WILLIAMSON, Mining Student, 20, Mitchell Street, Kircaldy.

Mr. Robert McLaren, M.P., was unanimously re-elected President for the ensuing year.

DISCUSSION OF MR. H. M. CADELL'S PAPER ON "COAL-MINING IN SPITSBERGEN."*

Prof. J. W. GREGORY (Glasgow University): I congratulate the Institute on the contribution of this most valuable summary and estimate of the present conditions of coal-mining in Spitsbergen, and on the beautiful and artistic sketches illustrating the paper. I am interested in the subject of the paper, because in 1896 I was a member of Sir Martin Conway's expedition which first crossed Spitsbergen, and I then mined some coal for its use. At that time it did not seem to me that economic mining in that country was a practical project, because the price of coal in Britain was then low too, and freights were too high. I quite support Mr. Cadell's view that there is nothing in the climatic conditions of Spitsbergen to prevent the mines from being worked satisfactorily all the year round. The iron-mines in Lapland are very much in the same position, and the wives of the officials there have told

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 119.

me that they much preferred the winter to the summer, because the electric light dispels the darkness, and it is altogether much pleasanter for them than in the summer. The only point in Mr. Cadell's paper to which I might offer a word of warning is in regard to the future mining conditions of Spitsbergen, and in particular to the suggestion made by him that these conditions will become easier. There is no doubt that most of the Spitsbergen glaciers are now on the decrease; but I doubt whether it is correct to say that they are all moribund. Mr. Cadell exhibited a photograph of one glacier with the "Chinese Wall" type of ending, and according to the general view if that glacier is not still advancing it is at least maintaining its position. Certainly some of the glaciers our party met with in 1896 were then advancing. Doubtless the great majority of the Spitsbergen glaciers were diminishing; but, on the other hand, some were increasing. Sir Martin Conway has called attention to indications that the Great Glacier, which he referred to as the "Ivory Gate," had only recently come down to its then position, and what years before had been an open valley it had filled with a wide field of ice. The importance of the question from the practical mining point of view is that sometimes for two or three years together nobody could get near the coal-mining area because of the ice-floes. If the climate is improving, then it may be hoped that the conditions to which I have referred may never recur; but the probability is that the mild seasons of the past four years are only a part of a mild cycle, and that when that cycle passes fully away we may expect severer and more ice-laden years. The miners in Spitsbergen ought not to be surprised if they find themselves hampered by ice conditions similar to those which occurred about 50 years ago.

Mr. R. W. Dron (Glasgow): Can Prof. Gregory throw some light on the geological problem involved here as to what the climate was in the Tertiary Age when the Spitsbergen coal-seams were being deposited? Although more of a geological question, and one in which mining engineers are not directly interested, it is, nevertheless, an important problem. Prof. Gregory at one time, I think, put forward the theory that the coal-seams might have been formed by the deposition of driftwood. There is undoubtedly a large quantity of driftwood, but I could never appreciate that as being the cause. The economic and scientific interest in the islands of Spitsbergen has resulted in many expeditions and publications, but this country has not yet taken a very prominent share in the work. Between 1758 and 1908 there were twenty-four expeditions from Sweden, resulting in 376 publications and sixty maps. These publications contain a great deal of interesting geological information, but very few of them have been translated. In the *Annales des Mines (Mémoires)*, Paris, 1914, Series 11, Vol. V., page 181, a list of nine analyses of coals from the Carboniferous Formation is given. The percentage average of these is as follows:—Humidity, 3·3; volatile matter, 28·7; coke, 47·0; and ash, 21·0.

Another series of eight samples gives an average humidity of 7·92 per cent. and of ash 13·94 per cent. Of the seventeen samples, the lowest in ash was one containing 6·7 per cent. and the highest 48 per cent. The coke produced was of mediocre quality. I am afraid that a coking coal of this quality will not be of much value in connexion with the iron-ore deposits in Northern Europe. The Tertiary coals, although of good quality otherwise, are not coking coals. The difficulty mentioned by Mr. Cadell on page 141 of the disintegrating effect of the weather will also

have a very important effect when considering these coals in competition with British coals. On the whole I do not think that the coal-trade in this country need feel uneasy regarding future competition with Spitsbergen.

Prof. J. W. Gregory: I never suggested that the whole of the material was driftwood. My suggestion was that the fossil tree-trunks found in the coal-seams might have arrived as driftwood thrown upon the shore.

Mr. H. M. Cadell (Bo'ness): With reference to Prof. Gregory's and Mr. Dron's remarks, there is no doubt that there was a time when the whole of Scotland was practically covered by an ice-sheet, such as covers Greenland still. Our climate has undergone a change, and there is the fact that we have had almost no ice in Scotland for some years now. The Scottish game of curling would never have been invented if our climate had been as mild as it has been during the past ten winters. The glaciers in North America have also been retreating on the whole during the last twenty years, and the change of climate, though slow, appears to be continuing steadily.

The further discussion of the paper was adjourned.

SECURING OF PIT-SHAFTS.

Mr. G. L. Kerr (Glasgow): Speaking as a member of the Institute, I desire to draw attention to the following announcement which appeared on page 159 of the *Iron and Coal Trades Review* of February 4th, 1921:—

> The Mines Department announce that Mr. W. C. Bridgeman, M.P. (Secretary for Mines) has appointed a Committee consisting of Mr. Thomas H. Mottram, C.B.E., H.M. Chief Inspector of Mines (Chairman), Mr. George A. Mitcheson, and Mr. Samuel Roebuck, M.B.E., to inquire and report whether any amendment is desirable in the provisions of the Coal Mines Act, 1911, as to the securing of shafts. The Secretary to the Committee, to whom communications should be addressed, is Mr. Charles D. Mottram, H.M. Inspector of Mines, 55, Francis Road, Edgbaston, Birmingham.

I think that most of the members will know why the appointment of this Committee has come about. The proposed investigation is very largely concerned with Scottish mines, and it will be for the members of this Institute to say whether it would be in order to protest against the composition of the Committee, composed as it is of an English colliery manager, a miners' leader, and H.M. Chief Inspector of Mines. A Committee to enquire into the securing of shafts in Scotland ought surely to have included amongst its members at least one Scottish representative.

The President (Mr. Robert McLaren): It appears to me that the Mines Department is setting up this Committee because it has been unable—in some courts at least—to bring about something it wanted. We in Scotland, in a question that so vitally affects us, ought to see that we get fair-play. Not only should there be an invitation to us to submit evidence, but our interests ought to be conserved in having one prominent mining man from Scotland on the Committee.

It was unanimously agreed that the Secretary should frame a resolution, protesting against the constitution of the Committee and its personnel, and putting forward a claim, on behalf of Scottish mining interests, for one representative on the Committee.

PHYSICAL WORK AND THE HUMAN MACHINE.

By Prof. HENRY BRIGGS, D.Sc.

Engineers have devoted the most painstaking attention to all the prime-movers used in general practice, except one. That exception is the human machine, the most ubiquitous, complex, delicate, expensive, and troublesome of all. Our very familiarity with that engine, and the knowledge which each of us possesses of its possibilities and of certain of its limitations, probably account to a large extent for the engineer's neglect of its study. The engineer, indeed, has been content to leave the matter entirely to the physiologist: he has not been willing to trespass on what he regarded as foreign ground. This view I now challenge, as I see no reason for barbed-wire fences between the sciences, and believe that an occasional venture across the border is stimulating to both sides. It is, for example, impossible to exaggerate the benefit mining has gained from the "raids" of one eminent physiologist to whom frequent reference is made; we can, at any rate, make an attempt to repay him in kind by an excursion into physiology.

Let us begin by comparing the more obvious attributes of the human machine with those of a mechanical prime-mover, and, as we are here concerned solely with physical work and its consequences, let us disregard the intellectual and emotional capacity of the former.

In the first place, the human being is a complete portable plant capable of consuming fuel, of developing heat-energy by virtue of the chemical union of oxygen with the carbon and hydrogen of that fuel, and of converting a part of this heat-energy into mechanical energy. So far, there is parallelism with a plant consisting of a boiler and steam-engine. The likeness is increased by the means adopted to reduce heat-loss; in both cases lagging of non-conducting material is employed, although the human being chooses to speak of his detachable lagging as clothing. Here, however, the resemblance ends.

The first difference between the cases—and it is an important one—is in regard to the temperature at which the chemical action between the fuel and the oxygen goes on. In the animal that temperature is low, and it is fixed with such definiteness that if it be altered even a few degrees up or down the scale the organism is totally disabled. An effect of the relatively low temperature at which the vital processes go on is that the amount of clothing worn must be made to vary with the external temperature; and in hot, damp situations where physical work is proceeding, the need to expose as much uncovered skin as possible is so imperative that the nature of the clothing affects both the capacity for work and the safety of the worker. Too much lagging in such circumstances may wreck the machine.

In the engine-and-boiler plant oxygen is consumed only in the boiler-furnace, not in the engine; but in the animal oxidation goes on all over the system, and in particular in muscles which are doing physical work. In both cases air is drawn in and used up continuously, and the boiler is

fed with fuel more or less continuously; but a man takes in his fuel-supply at relatively long intervals, and finds it almost essential to cease work during the stoking operation. He has a great storage capacity for fuel, but very little indeed for oxygen. If need be, he can work for a long time after his food-supply is cut off; but he dies in a few minutes if the oxygen-supply is stopped.

A striking difference is to be observed when air containing a high percentage of oxygen is used in place of normal air. A furnace, if fed with such enriched air, would burn with greater intensity; it would consume a larger weight of coal per square foot of grate area, and would produce little if any smoke; the steam output of the boiler would be increased. Nothing comparable with this occurs when a man breathes oxygen or highly-enriched air. Notwithstanding the widely-diffused popular belief to the contrary, he does not become intoxicated; there are no paroxysms of uncontrollable energy followed by lassitude. If the air of this room were suddenly changed to pure oxygen of the same temperature and hygrometric state, not one of us would be the wiser. When a mine-rescue apparatus is used, for example, the air inhaled often holds 80 and sometimes 90 per cent. of oxygen, and there is no deleterious effect on the wearer on that score. In my experiments on the subject, I found that, instead of a more rapid consumption of tissue, the breathing of cylinder oxygen made no difference in that respect when the person was at rest, and actually resulted in a slightly reduced consumption when he was doing work on a bicycle dynamometer. In other words, most people are a little more efficient as working machines when they respire enriched air. The human organism, then, takes what oxygen it needs from enriched air, and expires the remainder as though it were so much inert gas.

When a healthy man starts to do physical labour, the brain responds by accelerating the heart's speed and pressure of pumping, by dilating the arteries in and leading to the muscles doing the work, so as to increase the blood-circulation in those parts, and by enhancing the respiration (which is either deepened or quickened or both) in order to draw into the lungs the additional oxygen required. The extra supply of oxygen to the muscles at work is therefore derived, in the first place, from the passage of a greater amount of the gas per second from the air in the lungs into the blood, and, in the second place, from a more rapid transport of the oxygen, by the blood, from the lungs to the muscles. This question of the supply of oxygen to the muscles lies at the very root of the study of physical work. To make hard work possible, there must be an efficient co-operation of brain, heart, and lungs, in addition to a sufficient muscular development and sufficient nourishment.

Most of the writer's experiments were carried out with the ergometer of Prof. E. G. Martin. This is nothing more than a bicycle dynamometer, and consists of the frame, seat, pedals, and chain-drive of an ordinary bicycle supported on a wooden stand: the front wheel is absent, and in place of the back wheel there is a flywheel, round the rim of which passes a linen belt in the manner of the Prony brake. Adjustable strings are connected to the ends of the belt, and these in turn are attached to spring-balances. The gearing of the cycle is such that when the pedals are turned at 56 revolutions per minute the difference of the spring-balance readings multiplied by 1,000 gives the external work done in foot-pounds per minute. When a man is caused to do work on this machine, and his exhaled air is collected, metered, and analysed, certain

facts emerge.* It is seen, for instance, that the proportion of carbon dioxide in the expired breath is not constant; it is lowest at rest, and it rises as the rate of work increases until it reaches a maximum, and then, if still harder work be given, the proportion of carbon dioxide falls again. Thus, when set out on a graph (Curve *A*, Fig. 1, for example) the curve connecting exhaled-carbon-dioxide percentages (plotted as ordinates) and work done on the ergometer (abscissæ) assumes a domed form.

It will be convenient to speak of the rate of work corresponding to the maximal carbon-dioxide percentage as the "crest load." The dipping of the curve beyond the crest load is a certain indication of want of oxygen: at such heavy rates of exertion the muscles do not receive all the oxygen they are calling for; they become partially asphyxiated, and the work soon has to be stopped or much reduced. Up to the crest load, on the other hand, the evidence is to the effect that oxygenation is sufficient, and rates of exertion below the crest load can be supported for a considerable time. Certain of the terminology of the electrical engineer is useful in this connexion. When an electric motor is generating mechanical power at the rate for which it was designed, we say that it is working at "full load"; any rate of energy-output below full load is termed a "normal load" for the motor; whilst if it be called upon to develop power in excess of the full-load, the excess is spoken of as "over-load." With the human machine, then, the crest load is full load; anything under the crest load is a normal load, and anything above it an over-load. Although the crest load demarcates between a normal and an over-load, it must not be thought that that boundary is a fixed one for any given person; it varies in position according to the man's health; fatigue also moves it down the scale of exertion, and a task that began as a normal load may become an over-load towards the end of a hard shift. The effect of age is to move the boundary permanently down the scale, as may be gathered from a comparison of the *A* curves of Subject P.T.S. 1/24 (Fig. 7) and Subject P.T.S. 1/41 (Fig. 6). The former subject is a well-developed athletic youth of 18 with a crest load of 11,000 foot-pounds per minute, and the latter a man of 45 with a crest load of only 2,500 foot-pounds per minute. If stamina be defined as the capacity for sustained exertion, it will be evident that the crest load provides a relative measure of a subject's stamina at the time of the test.

There are factors in mining which affect a man's capacity for exertion, and which are seldom met with in other occupations. For example, the underground worker may have to labour in air containing carbon dioxide and an excess of nitrogen. The presence of carbon dioxide is generally supposed to militate considerably against effectual physical work, but experiment indicates that its influence in this respect has been exaggerated. The addition of, say, 2 per cent. of carbon dioxide *alone* to air is not detrimental. Its effect, indeed, is to augment the depth of breathing, and thus to promote rather than impede the transfer of

* A full discussion of these and other results and of the technique of the experiments will be found in the writer's paper entitled "Physical Exertion, Fitness and Breathing," *Journ. Physiol.*, 1920, vol. liv., page 292. Abbreviated accounts have been published in the *Second Report of the Mine Rescue Apparatus Research Committee*, 1920 (in which an illustration of the ergometer and other apparatus is given on pages 54-58), and in a short paper called "Fitness and Breathing during Exertion," *Journ. Physiol.*, 1919, vol. liii., *Proc. Physiol. Soc.*, page xxxviii.

oxygen to the blood.* A large proportion, such as 5 or 6 per cent., added *alone* to air certainly reduces the crest load and the stamina, and

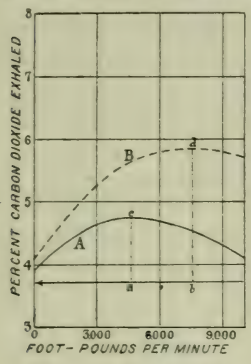

FIG. 1.—SUBJECT II.: A SEDENTARY SUBJECT.

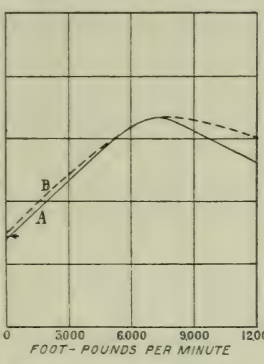

FIG. 2.—SUBJECT VIII.: AN ARMY INSTRUCTOR IN PHYSICAL DRILL.

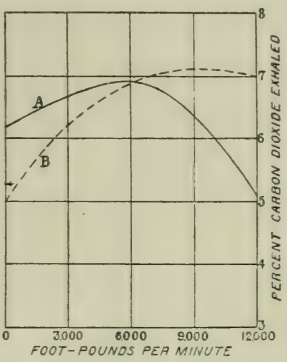

FIG. 3.—SUBJECT VII.: MANAGER OF A MINE WORKING STEEP SEAMS.

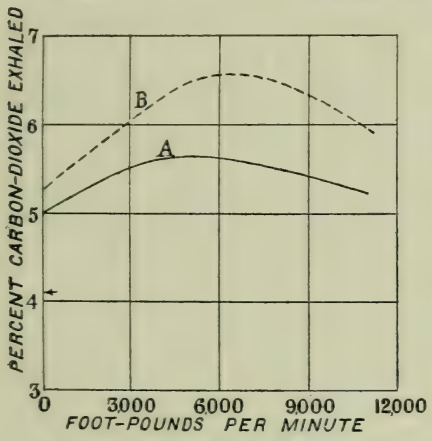

FIG. 4.—SUBJECT IV.: AN UNDER-MANAGER OF A MINE WORKING SEAMS OF MODERATE INCLINATION.

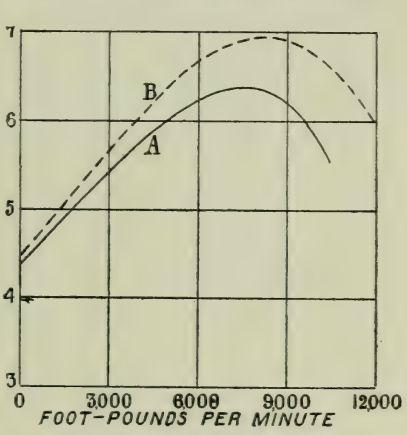

FIG. 5.—SUBJECT I.: A REPAIRER WORKING IN A STEEP SEAM.

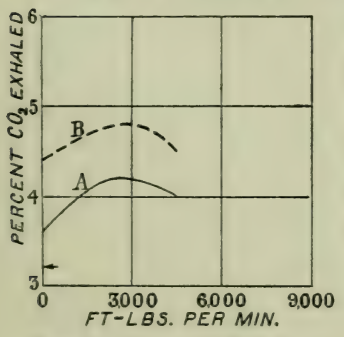

FIG. 6.—SUBJECT P.T.S. 1/41: A PAINTER, AGED 45.

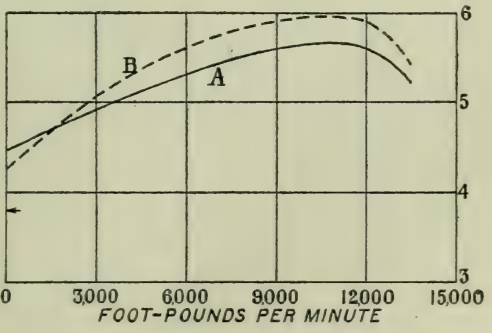

FIG. 7.—SUBJECT P.T.S. 1'24: A STUDENT, AGED 18.

brings on headache and fatigue; but in the percentages met with in the general body of the air under present-day mining conditions nothing is

*See also Haldane, Meakins, and Priestley, *Journ. Physiol.*, 1919, vol. lii., page 433.

to be feared from carbon dioxide *per se*. Unfortunately, it does not make its appearance unaccompanied in mine air : it is always associated with a much larger and variable amount of nitrogen. It is only in mine-rescue apparatus that we can deal with the gas as the only intruder in the air respired. Owing to it chiefly consisting of nitrogen, blackdamp in large proportion is generally more serious because of the diminution in oxygen which it causes than because of the carbon dioxide it contains. For those engaged in physical work it is more important that the percentage of oxygen in the air should not sink below 19 than that the carbon dioxide should not exceed $1\frac{1}{4}$ per cent. It is a handicap to have to carry out long-continued work in an atmosphere containing 19 per cent. of oxygen; in all but exceptionally fit young men a drop of even 2 per cent. in the oxygen-proportion reduces the worker's stamina and promotes fatigue. The oxygen-percentage turns out to be so much the more important of the two standards of Section 29 (3) of the Coal Mines Act that, for practical purposes, the carbon-dioxide limit might have been omitted.

A second factor influencing the miner's capacity for work is the wet-bulb temperature of the air. When that temperature approaches that of the blood, the system becomes less able to prevent an increase of body-temperature by the evaporation of sweat on the skin, and physical exertion, if persisted in under such conditions, may lead to death from heat-stroke. Our knowledge of the limits of human endurance under high wet-bulb temperatures is largely due to Dr. J. S. Haldane. The following sentences are taken from the *First Report of the Committee on "The Control of Atmospheric Conditions in Hot and Deep Mines"** :—

". . . . with the wet-bulb temperature at 78° continuous fairly hard work in still air was impossible. The wet-bulb temperature at which, with an air-current such as might be expected along a well-ventilated working-face, and an amount of work such as an average miner does, the normal body-temperature could be maintained was not determined, and remains to be ascertained. Judging, however, from such observations as have yet been made in hot and deep mines, this wet-bulb temperature is not much above 80°."

My own experiments have so opened my eyes to the difference between the trained and the untrained man that I am inclined to wonder whether sufficient regard has here been paid to the extraordinary adaptability of man. The experimenter is not usually inured to the type and conditions of labour upon which his observations are being made, and his own system and reactions are, therefore, not necessarily the best to observe. The effects of adaptation may be expected to be more striking the nearer one approaches to the limits of what is practicable to the human machine. There is evidence that those who are used to hot damp air can do hard work at temperatures exceeding 80° Fahr. Mr. Eric Davies has recorded that, in a fairly good air-current in the Morro Velho Mine, Brazil, regular work is proceeding at a wet-bulb temperature of 84° or 85° Fahr. On occasions it is higher ; in one instance, where hard labour such as loading and pushing trams was going on, it was 92·5°.†

Again, Mr. J. S. Hayes has described in a recent paper how coal-mining is proceeding in Nigeria, with the air at the faces saturated at a temperature of 87° to 90° Fahr.‡

* *Trans. Inst. M. E.*, 1919-1920, vol. lviii., pages 235-236.

† *Ibid.*, page 244; see also *Second Report* of the Committee, *Trans. Inst. M. E.*, 1919-1920, vol. lviii., page 323.

‡ "The Development of the Udi Coalfield, Nigeria," *Trans. Inst. M. E.*, 1919-1920, vol. lix., page 359.

It may be objected that in these instances native labour is employed. That is so; but the native is subject to the same physiological laws as ourselves. It is perhaps worth remarking that physical exertion at ordinary external temperatures induces a rise in body-temperature which is seemingly as much a normal concomitant of the exercise as the augmentation of blood-circulation and respiration. There is apparently nothing uncommon in the body-temperature rising to 102° Fahr. during exertion, and greater increases have been recorded.* This increase in temperature is said to serve a useful purpose in facilitating the transfer of oxygen from the blood to the muscles, and in hot places it assists evaporation from the skin.

The great reduction in efficiency of the human machine which results from a high wet-bulb temperature is accountable, then, in the first place to the difficulty of keeping down the body-temperature. I wish to suggest a possible second cause, namely, that the hot damp air may impair the passage of oxygen from the air in the lungs to the blood. A recent experience lends colour to that view. A rescue-brigade were exercising with breathing-apparatus in a road in the Niddrie Colliery. A steam-pipe ran along the road; some steam was escaping, bringing the air to saturation-point at a temperature of 85° Fahr. After more than an hour's light work, a halt was called, and the Instructor (Mr. D. Davidson) advised the men to take out their mouthpieces and rest. They did so, but very soon slipped them back again, one by one. They preferred to breathe air from the apparatus—which by that time would also be saturated and of at least as high a temperature as the outer atmosphere —rather than fresh air from the road. The air of the apparatus would contain 70 or 80 per cent. of oxygen; it would, therefore, be more comfortable to inhale than normal saturated air at this high temperature if there were any difficulty in getting a proper oxygen-supply from the latter. This seems to be a point calling for investigation.

A fact which appeared during the research on mine-rescue apparatus was the high level of the expired-carbon-dioxide percentage of a miner performing a piece of work to which he was accustomed, as compared with that of a person to whom that task was strange. In some instances the carbon-dioxide percentage in the former case was nearly double that in the latter. The percentages of oxygen taken out of the air by the lungs of the two men in exchange for carbon dioxide were in similar ratio. In other words, the expert workman uses up the air he breathes more completely than the inexpert workman, and he breathes a correspondingly smaller volume per minute. There are exceptions to this rule, but they are few and far between. The adept has taught himself to carry out his duties with less respiratory exertion than the man who is inexperienced in that kind of labour, and therefore he is less apt to suffer from respiratory fatigue. This process of adaptation of the machine to its special duties is often most striking.† As an instance in point, let us take the case of an underground official transferred from flat to steep workings. At first, and indeed for a considerable time, he finds the work of going his rounds specially hard, and that he is inferior to another man of similar physique who has been used to steep workings for several years. But in time, if the first man is not too old, his lungs and muscles become adapted to the new conditions: his expired-carbon-dioxide percentage becomes

* *Physiology of Muscular Exercise*, by F. A. Bainbridge, 1919. page 18.

†See also Jules Amar, *Comptes Rendus de l'Académie des Sciences*, August 9th, 1920. This investigator found, in testing apprentices in engineering shops, that the respiratory economy increased with the degree of training attained.

adjusted to a new and higher level; he uses less air and uses it more thoroughly (compare the *A* curves of the two mine officials, Subjects IV. and VII.; the former works in fairly flat and the latter in steep seams).

The importance of *physical fitness* can scarcely be exaggerated in its bearing upon manual work. Other things being equal, the output of the fit man exceeds that of the unfit man, and he performs the day's labour with less fatigue. Physical fitness and dexterity often go together, but they should not be confused. The latter, which has already been discussed in some measure, is the result of training the brain and the muscles in relation to a special task; it can only be acquired by practice at that task. The training which leads to deftness teaches how to obtain the desired effect with a minimum of muscular effort, and therefore with a minimum waste of energy in the form of heat; it also leads to a strengthening of the group of muscles most adapted to perform the work. Fitness, on the other hand, is a much more general bodily attribute than this; it can be developed—and, indeed, is best developed—by all-round exercise, combined with a close attention to certain common-sense rules of living. When dexterity and fitness go hand in hand, we have the human machine in its most efficient state.*

The experiments carried out in Edinburgh on a large number of men from many walks of life have thrown considerable light on the subject of physical fitness. Fitness, indeed, has proved to be the efficiency of oxygenation of brain, heart, and muscles during exertion.

In the accompanying graphs (Figs. 1 to 7) the *A* curves were determined when the subjects breathed normal air, the *B* curves when they breathed almost pure oxygen. So far, reference has been to the former set only; we are now in a position to compare the two. Fig. 1 (Subject II.) is the record of a sedentary person of rather low fitness, and it will be observed that his *A* and *B* curves are far apart. Fig. 2 (Subject VIII.) relates to a sergeant-instructor in physical drill and a heavy-weight lifter; he was selected for the tests by the Superintendent, P. and B.T., Scottish Command, as representing the best physical material that the army can produce, and he was certainly the fittest man tested. The curves in his case are almost coincident, and their crests actually do coincide: it is only with over-loads (that is, those higher than the crest load) that the *B* curve takes the upper place. Such a man as the latter derives no benefit from breathing highly-enriched air during exertion, while Subject II. gets a great deal of help therefrom. The degree of assistance from extra oxygen, indeed, is inversely as the fitness, and the curves enable physical fitness to be evaluated. This is done by drawing a horizontal *ab* (Fig. 1), at the level of the carbon-dioxide percentage in the expired breath at rest, when the man breathes normal air, and then dividing the intercept *ac* by the intercept *bd* (in each of the other graphs, the carbon-dioxide percentage at rest is indicated by an arrow-head). By this method the fitness of the sedentary subject (Fig. 1) is 46 per cent., and that of Subject VIII. 100 per cent. So far as my observations went, the fitness of the healthy working miner is above 70 per cent., although I did not examine any underground worker over 45 years of age. The miners and officials who were tested were members of mine-rescue brigades. In one instance a member of a resident rescue-corps was tested: his fitness was found to be only 56 per cent. It appeared very likely that his fitness had deteriorated since he left the mines.

* It was agreed at the start that the intellectual aspect was to be kept out of the argument.

The method of measuring fitness here described was adopted for army purposes in 1918, and put into use at the Physical Test Station, Edinburgh. An analysis is given below of eighty-four persons tested at the station. They were drawn from all grades of society, and were mostly under 40 years of age.

					Per cent.	Per cent.
Proportion of	men	whose	physical	fitness was below	40	*Nil.*
do.	do.	do.	do.	between	40 and 50:	7
do.	do.	do.	do.	do.	50 ,, 60:	12
do.	do.	do.	do.	do.	60 ,, 70:	27
do.	do.	do.	do.	do.	70 ,, 80:	23
do.	do.	do.	do.	do.	80 ,, 90:	24
do.	do.	do.	do.	do.	90 ,, 100:	7

Recent regulations require would-be mine-rescue men to undergo a physical as well as a medical examination before they can be accepted for training. The system of testing already described enables a physical examination to be made and fitness and stamina to be determined quantitatively.

The mechanical efficiency of the human machine has been investigated by several physiologists. Their results are in fair agreement with each other and with my own. The usual efficiency to be determined is the "gross" or overall efficiency, and the most convenient way of measuring the input of energy is from the oxygen-consumption. The consumption of a cubic foot of oxygen results in the development of a definite number of heat-units (which are easily expressed as units of work), depending upon the proportion of the oxygen going to form carbon dioxide and the proportion going to form water. The gross efficiency is ascertained by dividing the figure so obtained by the external work done while the oxygen was being consumed. To return to the analogy of the early part of this paper: the gross efficiency is equivalent to the brake-horsepower developed by the engine divided by the power put into the boiler-furnace and determined from the rate of burning of the coal and its calorific value.

Considerable difficulty is encountered in finding efficiency when the subject is dealing with an over-load, owing to the fact that, with such a degree of exertion, the oxygen required to support the exercise is not all taken in during the period of exertion; a great deal is supplied during the panting which ensues after the work ceases. The breathing does not quite settle down for several hours after a short spell of very hard labour. The state of affairs resembles that arising when the engine of the analogue is given an unusually heavy task and succeeds in doing it, for a short time, by drawing upon the steam stored in the steam-space of the boiler: after which effort it is compelled to stop or slow down until the boiler pressure and steam-reserve have been restored. If, in these circumstances, the horsepower transmitted by the crankshaft were divided by the horse-power generated as heat in the furnace while the engine was running, an erroneously high efficiency would be obtained. When the gross efficiency of the human machine is corrected, when necessary, by means of the excess of oxygen consumed during the post-work period, and efficiencies as ordinates are plotted against loads as abscissæ, a domed-shaped curve again results. In other words, the gross efficiency increases with the load up to a maximum, and then falls again. The load at which the maximum efficiency is obtainable is the same as, or nearly the same as, the "crest load" as above defined. For most people the maximum efficiency, when breathing normal air, is in or near the region of 20 to 23 per cent. With highly-trained men, as was observed

by Benedict and Cathcart, the efficiency is increased, and these workers have recorded one of 33 per cent. The highest efficiency ascertained during my own experiments was 37 per cent.; it was the maximal value of a very remarkable athlete, G. P. Miller, of the Heart of Midlothian Football Club, when doing work on the ergometer at the rate of 6,500 foot-pounds per minute. Bearing in mind that the overall efficiency of a small non-condensing engine and boiler is usually less than 2 per cent., that that of a large high-class condensing engine and boiler is about 8 per cent., and that probably only with the Diesel oil-engine does the gross efficiency reach or occasionally exceed 20 per cent., it has to be allowed that the human machine stands on a high level among heat-engines. Unfortunately, the human engine cannot be worked long at its most efficient rate: fatigue reduces the efficiency. It is doubtful whether the gross efficiency of most heavy manual labour exceeds 10 per cent.

Some kinds of work are dealt with more efficiently than others: most healthy people are especially efficient in climbing stairs; rather less so on the ergometer, and still less so in climbing a mine incline, where the "going" is relatively rough and sometimes slippery. In general, the efficiency is a little higher when breathing oxygen than when breathing air; the fit man's efficiency exceeds that of the unfit man; and the efficiency of a person working at a job to which he is accustomed is greater than that of a man carrying out the same task when that task is strange to him.

The process of investigation of which the foregoing account gives an indication is capable of being much extended. Efficiency-studies on the human machine have been made with much care in the United States of America, and they have considerably influenced workshop arrangements and organization. Nor are they altogether neglected in this country, where, during the war, useful work was done, for example, in shell-filling factories on the relation between hours and output. This, and many other problems concerning the miner and his work, await the attack of the investigator, who is sometimes able to answer after a few months of experiment questions that have perplexed a generation.

In conclusion, I wish to acknowledge the very valuable assistance rendered in the course of the experiments alluded to by Miss Elizabeth Gilchrist, M.A., B.Sc., and Mr. D. Penman, B.Sc., Government research workers.

The PRESIDENT (Mr. Robert McLaren, M.P.): I cannot quite conceive how Dr. Haldane should object to the use of the term "human machine" as applicable to men and work, because it seems to me you could not have a better phrase. I think the author and his assistants deserve great credit for having tackled this interesting problem, because a great deal is being written in the newspapers about the capacity of certain classes for work. It is quite interesting to learn what the human machine is capable of doing, but it is another thing to get it to do that work.

The further discussion of the paper was adjourned.

THE MINING INSTITUTE OF SCOTLAND.

SPECIAL GENERAL MEETING,

HELD AT THE HERIOT-WATT COLLEGE, EDINBURGH,
FEBRUARY 5TH, 1921.

MR. ROBERT McLAREN, M.P., PRESIDENT, IN THE CHAIR.

ALTERATION OF BYE-LAWS.

At the close of the Ordinary General Meeting, a Special General Meeting of the members was held to consider the following alterations to the Bye-laws :—

25.—The annual subscription of each of the various classes of members as classified in Bye-Law 2 shall be as follows :—

(*a*) MEMBERS—(1) Holders of a first-class certificate either acting as resident responsible colliery managers or in positions subordinate to acting colliery managers; (2) teachers of mining; (3) those in the employment of mining, metallurgical, or mechanical engineers, or employed in a similar capacity at collieries in Great Britain and Ireland, £2 2s.; in British colonies or foreign countries, £3 3s.; (4) all others of this class, £3 3s; (5) subscribing firms presently giving the minimum subscription of £2 2s. be asked to subscribe a minimum of £3 3s.

(*b*) ASSOCIATE MEMBERS—(1) Persons who are engaged in pursuits of a character leading up to qualification for membership, £1 15s.; all others of this class, £3 3s.

(*c*) ASSOCIATES—(1) Persons who are engaged in pursuits of a character leading up to membership, £1 10s.; (2) all others of this class, £3 3s.

26.—Ordinary Members and Associate Members may compound for all future payments by a payment of £40, or on such conditions as the Council may in writing accept.

Mr. H. M. CADELL moved and Mr. R. W. DRON seconded a resolution approving of the proposed alterations, and this was carried unanimously.

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

GENERAL MEETING,
Held at The University, Sheffield, February 17th, 1921.

Mr. J. H. W. LAVERICK, President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen were declared duly elected :—

Members—

Mr. George Norman Longbotham, King's Chambers, Angel Street, Sheffield.
Mr. Michael MacDermott, Hackenthorpe, Sheffield.
Mr. Albert Mellor, 15, Regent Gardens, Barnsley.
Mr. Albert Edward Rose, Stone Lea, Rawmarsh Hill, Parkgate, Rotherham.
Mr. Richard Vernon Wheeler, D.Sc., The University, St. George's Square, Sheffield.

Associate Member—

Mr. John Leslie Smith, Sherburn House, Cawood, Selby.

Associates—

Mr. Norman Evers, 14, Kenilworth Avenue, Harrogate.
Mr. Arthur Shaw, 251, Rose Cottages, Handsworth, Sheffield.

Student—

Mr. Arthur Hayden Booth, Laburnum Cottage, Old Whittington, Chesterfield.

DISCUSSION OF DR. R. LESSING'S PAPER ON "STUDIES IN THE DISTRIBUTION OF MINERAL MATTER IN COAL."*

Dr. R. Lessing (London), after exhibiting lantern-slides illustrating his paper, said : These slides are intended to show the coking qualities of four constituents of coal. The products illustrated were obtained in a small electric furnace that I devised some years ago, which confines the coal and afterwards the coke in a closed space and produces a cylinder of coke which is more characteristic for each coal than that ordinarily obtained in the platinum crucible. The slides shown indicate clearly these differing characteristics, both in formation and in content. The fusain is absolutely non-coking, and remains in the form of powder even when heated to 900° or 1,000° Cent. Durain is very slightly coking, whilst clarain and vitrain possess good coking properties and fuse or sinter very easily. The vitrain exhibits the mushroom-shape characteristic of some of the coals I have previously shown, and I think it probable that coals which show that mushroom shape will be very rich in vitrain. These tests will make clear the general characteristics and differences between the various ingredients which lead on to the examination of their ashes.

Dr. R. V. Wheeler (Sheffield University): I was particularly interested ten or twelve years ago in gas-producer practice, and had charge of a gas-producing plant, and if I had known at that time of Dr.

* *Trans. Inst. M. E.*, 1920-1921, vol. lx , page 288.

Lessing's results I should have been saved a great deal of trouble. I was then using washed nuts at 6s. per ton, which seemed rather too expensive, so I thought that I would try washed " beans " and " peas," the cost of which was less. An additional reason for trying smaller sized coal was that as I was working on rather a low load, the resistance in the bed of the producer to the air-blast was not sufficient for efficient working, and I hoped that with the finer fuel the working would be improved. The washed nuts contained about 2 per cent. of ash, which was not very fusible, and did not clinker badly. The washed beans, which contained about 4 per cent. of ash, were very satisfactory, and increased the resistance to the air-blast, as expected. When I tried washed peas, however, the producer clinkered up after working two hours. The amount of ash in the peas was about 8 per cent., but it differed entirely in its chemical composition from that obtained in the nuts and beans from the same seam. If I had at that time known of Dr. Lessing's work I should have looked very carefully into the chemical composition of the ash before trying the finer coal in the gas-producer. I quote this experience as an instance of the practical application of Dr. Lessing's researches.

Capt. F. S. Sinnatt (Manchester College of Technology): I am very much impressed with the valuable work that Dr. Lessing has done, which is really essential in order to obtain a thorough knowledge of coal-substances and inorganic constituents. I have tried to form some impression concerning the white partings. I emphasize this to call attention to the fact that they contain iron in the ferrous condition in an abnormal state, and, as is commonly known, when the partings are exposed to the air they gradually turn red. The rate at which they turn red is very interesting. Some of the coals in Lancashire are judged by the presence of these white partings in the surface. The turning red really means oxidation, and that oxidation brings about an increase in volume of the white partings, with the result that the coal tends to burst. The tendency to burst exposes other surfaces, and the result is that if a seam be examined it is found frequently that the red colour, which is not natural, can be discovered very deep in the coal. A further point is that most of the other iron in the coal, as distinct from the pyrites, is probably present as ferrous carbonate; in fact, it appears that practically all the iron is present as ferrous compounds, and therefore as these ankerites rapidly turn red it is quite possible that the ferrous iron which cannot be seen is also turning red. In a previous discussion it was suggested that probably one of the reasons for the more rapid oxidation of the coal was the fact that it contained these ferrous compounds, which might act as a catalyst. The white partings also contain manganese, and, as everybody in the chemical industry is aware, that is one of the most vigorous catalysts. This leads to the suggestion that these constituents may constitute one of the sources of the heating of the coal at a stage before the pyrites begin to act. The pyrites may also have an important action.

The next point to which I wish to refer is in regard to the fusain—the black part of coal. Taking some ordinary Lancashire coal, I found that 90 per cent. of the surfaces parallel to the bedding-plane were covered with fusain; these are exposed to the air in the mines, and consequently the dust carried away will be rich in fusain. That led me to examine a number of dusts actually found in the mine, which I found contained up to 30 per cent. of fusain. Although my investigations differ from those of Mr. Ivon Graham, I think it safe to assume, until one knows whether or not mine dust does contain fusain, that it is

there. I allowed a tank containing 100 tons of slurry to drain off,* then cut a section, examined it inch by inch, in one of Dr. Lessing's apparatus (which are the best obtainable), and found the average percentage of fusain present to be about 25. The top 6 inches of this slurry contained 50 per cent. of fusain, and the coke obtained from this was completely non-caking. The coal from which it was derived was comparatively good caking coal, so that the 50 per cent. of fusain mixed with the coal-dust had destroyed its caking power completely. Does this really mean that fusain will destroy the caking power of coal? I want particularly to draw attention to the fact that one unit of ordinary fusain mixed with one unit of coal did not destroy the caking power. Why? It is because the destruction of the caking power depends not so much upon the weight of the fusain as upon its degree of fineness; in other words, the finer it is the more it has this destructive action; so that if the fusain as ordinarily obtained has not so much influence on the slurry-tank, it may have this destructive action after it has passed through the washery and become pulverized to a very fine state. While it took about nine parts of 1/60 to 1/90-mesh fusain to destroy the coking power of this particular coal, I found that in its finely-divided state it took only one part. One must recognize that the degree of fineness has to be taken into account, otherwise if the material is not distributed most carefully in the coal there will be found very great weakness in the coke produced.

Prof. W. G. Fearnsides (Sheffield University): Capt. Sinnatt has read an important paper before the Society of Chemical Industry† on the "white partings" which abound in Lancashire coal, and has reintroduced the term "ankerite." I agree that the fact that the spar which fills the cleat cracks contains a certain amount of ferrous carbonate is important; but it should be borne in mind that the analyses of the cleat-spars found in Lancashire coals are not everywhere applicable in other coalfields. In the Yorkshire district, more especially in those parts of it where the coal is salty, the more usual spar mineral is a mixture of dolomite with excess of calcite and often some pyrites. Capt. Sinnatt has expressed the opinion that ferrous carbonate is the most active form in which iron occurs in coal, but the type of material locally known as "brasses" is certainly also a very active material, and its presence or absence certainly affects the rate at which the coal will burn.

Crystalline pyrites as well-formed striated cubes, or as pyritohedra, is almost unknown as a filling of the joint-cracks, and is not common in the midst of the coal. So far as my experience goes, I have not had an opportunity to prove the presence of marcasite in coal. The materials termed "brasses" are neither pure pyrites nor pure marcasite, but non-homogeneous mixtures or solid solutions of several sulphides of iron, and when these are exposed to the action of damp air or water carrying oxygen in solution, this non-homogeniety asserts itself, and with resulting battery action chemical corrosion is set up.

I am with Dr. Wheeler also able to testify to the practical usefulness of Dr. Lessing's paper. As Professor in charge of the University Department dealing with refractories, I have had opportunities of inspecting combustion-chambers where many varieties of solid fuel have

* See "Coal Dust and Fusain," by F. S. Sinnatt, H. Stern, and F. Bayley. *Bulletin No. 5, Lancashire and Cheshire Coal Research Association*, 1920.

† "The Inorganic Constitutents of Coal with Special Reference to Lancashire Seams," by F. S. Sinnatt, A. Grounds, and F. Bayley. *Journ. Soc. Chem. Indus.*, 1921, vol. xl., pages 1T-4T.

been burnt in contact with many sorts of bricks, and have formed the opinion that very few users of fuel have recognized how immensely important is the composition of the ash from the point of view of the cost of the maintenance of furnace-linings. I have recently been watching the experimental introduction of powdered fuel for steam-raising on a large scale. I have already seen it proved that the commercial success of powdered fuel depends very largely on whether the incombustible material—that is, the ash—is or is not fusible at the instant the combustion-products pass out of the combustion-chamber into the boiler-flues. If at that instant the ash is a dust and free from liquid, combustion can proceed continuously. If it is liquid, it forms into drops, and can be persuaded to collect on the walls, and, effecting more or less corrosion of the brick surfaces, to run down into a slag-pocket. If it is neither a mobile liquid nor yet a dust, it accumulates as clinker or as viscous slag, which tends to pile up on the bridge or under the arch of the outlet-flue, and so compels not infrequent stoppages. It will be necessary for those who are interested in the industrial application of powdered fuel to know beforehand the composition of the ash of all the several grades of fuel which they send to the powdering mill; and obviously, therefore, it is of importance that those who supply the coal should know the composition of the ash of the various grades of coal which they have to offer.

Mr. S. J. Rayner (Canklow): I should like Prof. Fearnsides or Capt. Sinnatt to give the reasons for the existence of the white substances between the planes of cleavage in the coal. Is the presence of the white substances essential to the formation of the cleat, or, in other words, are they a cause or a consequence of the cleavage in the coal?

Capt. Sinnatt: There appears to be quite a number of different forms of pyrites in Lancashire coal. I have examined one of these with extreme care, and my observations were on practically parallel lines with those of Prof. Fearnsides. On taking a fresh surface of that coal and examining one of the globules in section under the microscope, it became extremely soft and plastic in two hours. That is really one of the forms of iron sulphide of which Prof. Fearnsides spoke. What its real nature is is a matter for further investigation.

Dr. R. Lessing: I am very pleased to hear of Dr. Wheeler's practical experience in connexion with the composition and behaviour of ashes from various sizes of coal. This is a practical test which indicates the possibilities of the work I have brought before your notice. It shows to what extent study is required in order to clear up what may appear to the ordinary practical man very minor or negligible points, but which, in fact, are quite important. In the concluding paragraph of my paper I touched on the fusibility of the ash in gas-producers. I find, in connexion with gas-producers now being erected for the complete gasification of coal—the combined retort and producer plant—that it is exceedingly important to study the composition of the ash; the mere fusibility of the average sample does not give sufficient information, because when coal is put into the retort or producer we do not obtain a complete mixture such as is got in the analysis. There are lumps composed of various layers of different ashes, which may or may not fuse, each by itself, but which have an important bearing upon each other; and when we get the more fusible portion of the ash in a very small size, like the pea, we are simply courting disaster. The producer will be blocked up in a very few hours, and resort must be had to the pick-axe, instead of relying on the smooth running down of the charge.

Capt. Sinnatt has referred to the white partings, which are a very important portion of the mineral constitutents of coal, and one which rather interferes with the clearing-up of some of the problems. Hitherto we have been accustomed to talk about the inherent ash of coal and the dirt, or the extraneous ash. It is, however, very difficult to discriminate between these. If we are to regard only that amount of ash which is absolutely inherent in the coal-substance, it will be found to be very small indeed. As I pointed out in the paper, a clean coking coal does not contain more than 1½ to 2 per cent. of ash, and I do not think it is out of the range of probability that within a very few years such a coal will be put on the market.

The question of powdered fuel has been mentioned; in that case it is absolutely essential to have a coal as free from ash as possible. Whether the inherent ash that we cannot remove from the coal by present means is not just the most fusible part which interferes very much in the use of powdered fuel is difficult to say. Personally, I believe it to be so; but for most purposes it is absolutely essential to have the cleanest coal possible, and this can be effected, as foreshadowed in the previous discussion, with no loss either to the coal-producer or the coal-consumer. It cannot be to the advantage of anybody concerned, and certainly not to the community in general, to carry up and down the country ash to the extent of 10 per cent. or more of the coal-supply. I believe that ash-removal even for purposes of steam-raising or for domestic consumption will be part of the daily routine of collieries. It will, however, be necessary first to study how this is to be done, and which part of the mineral portion should and could be eliminated. I am afraid that at present we are not quite prepared for that ambitious task.

To return to the question of white partings, these are not inherent in the coal-substance, but are rather one of the sources of the dirt. They are not the kind of dirt brought into the coal from the roof or the floor of the coal-seam, but in my opinion—and I believe there is general agreement on this point—they are introduced into the coal by infiltration.

Mr. Rayner has asked whether the appearance of the cleavage—leaving quite undiscussed the question whether it is lime or iron—is the cause or the effect of the fracture of the coal. Even here the information available is very meagre, but there is sufficient evidence to warrant one to say with a certain amount of confidence that this substance was deposited by and from water, most likely after the cracks had been formed by some geological occurrence. That being so, it is merely a question whether the water which entered those fissures was of a calcareous or of a chalybeate nature. That depends upon the strata through which the water had percolated before it got into the coal. Prof. Fearnsides told me this morning that in Spitsbergen there are cleats which are as yet unoccupied, and others which are filled with ice; so that it is quite conceivable—and, indeed, very probable—that the cleats or partings have been deposited by water. This brings me to the question of their composition. Some of them are almost entirely composed of calcium carbonate or dolomite; in other cases they contain a great deal of iron. The South Yorkshire Coalfield is very characteristic in that it contains over and above the iron, which is of white appearance and very similar to calcium carbonate (whether it is called "ankerite" or some other name), the "brasses" referred to by Prof. Fearnsides, not only in the form of crystals or pyrites, but in sheets. It appears to me that the explanation I touched upon at the previous

meeting might apply to the present case—that the iron was introduced into the cracks along with the water in some form or other, most likely as a carbonate or bi-carbonate in ferrous condition, or bi-carbonate similar to the lime, and when there or on its way was acted upon by the sulphur from the organic portion of the coal. In doing so, it would be transformed into one or other of the various sulphides of iron, according to the degree to which this sulphidation had gone and the point at which it was stopped or when oxidation set in. It is known that sulphur must have been present, and that sulphur, interacting with the iron deposited from the water, would produce sulphide, and, according to the length of time or degree of action, would also be responsible for the sulphides in different forms. Which form they took would be largely a question of time, and whether marcasite or pyrrhotine is there is very uncertain; I should not be surprised if marcasite existed in certain places.

Capt. Sinnatt also referred to the fusain in the dust, and, as mentioned by Mr. Graham at the previous meeting, that road-dust does not contain as much fusain as he expected. There is one point which I omitted to advance on that question. Most likely road-dust is somewhat different from dust deposited on the upper portions of the roads or near the workings of the mine, because a very fair amount of the coal must be crushed and pulverized by attrition under the wheels of the tubs, and that would be the comparatively harder portion of the coal—in fact, coal as distinct from fusain. This would also explain the fact that one does not get pure fusain in slurry from washeries. The degree of fineness and its influence on coking was brought out in the slide. Fineness of particle is undoubtedly a most important point in connexion with coking, as all practical coking people know. It is one of the reasons why metallurgical coke is different from gas-coke, because in metallurgical coke fineness of particle is very much more usual than in coke from gas-retorts, although this is not the only reason for the difference, and conditions of compression, temperature, and other factors enter into it.

Prof. Fearnsides has referred to the importance of ash analysis from the point of view of the refractory materials. Refractories are not regarded to-day as being likely to stand the test of time. In many cases the firebrick in steel furnaces, coke-ovens, and in ordinary fireboxes is not expected to last more than a few months. Improvements have been made, but if account is not taken of the mineral matter in the coal, it is hopeless to expect the vessels in which metallurgical operations are carried out to last any length of time. This brings me to the question of alkali tests raised by Prof. Fearnsides at the previous meeting, but which I did not then answer. I frankly confess that these were not carried out in the present research, because it would have meant still more laborious and lengthy analyses. It was simply a matter of expediency that they were left undetermined, but in the original work which I did on coal ingredients the alkalies were actually estimated, and it was then found that they were higher in the inherent ash, whilst in the adventitious deposits and in the durain the alkalies were rather small. It depends also, of course, on the saline character of the water with which the coal has been most recently in contact. How important the determination of the alkalies and the salt in coal is all those in charge of coke-ovens know well enough.

The discussion of the paper was closed.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
Held in the Rooms of the Society, Queen's Chambers, 5, John Dalton Street, Manchester, February 8th, 1921.

Mr. A. J. A. ORCHARD, Past-President, in the Chair.

THE MINING, MANUFACTURE, AND USES OF BARYTES IN THE NEIGHBOURHOOD OF APPLEBY, WESTMORLAND.

By VINCENT BRAMALL.

The area taken in this paper is the range of Fells on the north-eastern side of Appleby from south of Cross Fell on the Cumberland border to Stainmore on the Yorkshire border. Starting at the north, the first of the mining properties is the Silverband group on the Little Dunfell and Great Dunfell. In this group there are about eight strongly-defined lead-veins, most of which are rich in barytes. The general direction of these veins is from east to west, and many of these have been worked for long distances. The principal vein is the Silverband, which occurs in a throw or fault of about 11 fathoms. The lead-ore (" galena ") from this vein is rich in silver, and carries up to 15 ounces per ton.

This group and most of the other mines for several miles around were worked by the London Lead Company more than a century ago, but were closed down in the eighties. I produce for inspection a copy of an old plan, dated 1820, showing " Mineral Ground Leased by the Corporation of the Govnr. & Co. for smelting down lead with Pit Coal, Pea Coal." The area on the plan is bounded by the counties of Cumberland, Durham, and Yorkshire.

The productive measures are found in the Yoredale Series of limestones, all of which occur at the top of the Fells, and consequently mining is carried out at high altitudes. The Silverband Mines are from 2,300 to 2,800 feet above sea-level, the Great Limestone is at the top, and the barytes vein crops out in places on its surface in wide patches. This vein has been proved for several hundred feet in depth, and consists mostly of barytes, which varies from 10 to 60 feet in thickness. There are thus several hundred thousand tons of this mineral to be worked. Unfortunately, a considerable amount of the barytes is badly stained, and although containing 95 per cent. and over of barium sulphate ($BaSO_4$), it is bad for bleaching and only suitable for use as crude barytes.

The old method of mining was, on locating a vein, to " hush " it out. It will be noted on the old plan exhibited that quite a number of " hushes " are marked. The procedure was to make a dam at the top of the vein so as to form a pound for water: the ground on the course of the vein was then broken up, and the sluice of the dam opened wide to let the water flood down the " hush." The water washed away all the *débris* and left the lead, which was then gathered up and removed, the process being repeated until the " hush " reached so great a depth as

to be unsafe or unprofitable. Some of these " hushes " were from 30 to 40 feet deep, and it then became necessary to drive levels or drifts into the mountain side in order to cut the vein. I have recently re-opened several of these drifts, and found them in practically the same condition as when driven, some of the larch timber being perfectly sound. The sleepers, which must have been in the drift from 50 to 60 years, were fit to be used again. The old rails, of which there are a few left, were of cast-iron, about 3 feet long, and were dropped into slots in the chairs. The top level, which I am told goes into a solid mass of barytes, is now being opened out, and as these mines have been worked for lead only and the barytes or, as the miners call it, " caulk " was then considered of no value, it was left in the mine. A vein of barium carbonate or witherite also occurs in this level. In the lowest level are two very large " shakes " or natural caverns. One of these, I am told, extends for a considerable distance, and takes several hours to explore; unless care is taken to mark the road, one is liable to lose one's way.

A large body of brown iron-ore, about 13 feet wide, containing about 42 per cent. of iron, and running alongside the Silverband Vein, is found on this property, and crops out to the surface. I have also found manganese peroxide (pyrolusite) on the dump, which on analysis yielded about 50 per cent. of manganese. This, I am informed, was found in a bed about 6 to 8 feet thick, and has the appearance of small coke. I do not know whether any large quantity exists or whether this is only a local deposit.

The next group consists of the Dufton and Threlkeld Mines, situated about 2 miles to the south of the Silverband Vein. These were worked for lead, and were abandoned at the same time as the other mines in the district, but like the Silverband group they are not exhausted. The veins proved are about eight in number, and generally run east to west. They appear to be very bunchy, the galena often occurring in large pockets and in other places in nodules surrounded by barytes. I have found many lumps of pure galena weighing over a stone. No blend or other metallic ore, with the exception of ironstone, is to be found in any of these veins, and owing to the softness of the barytes milling is rendered easy. This group was worked for barytes for some time, but, owing to foreign competition, the mines were closed again about 20 years ago.

The question of transport was and still is a serious one. Formerly the ore was carried in panniers on Galloway ponies, and when lead was only £8 or £10 a ton there could not have been much margin of profit. There are now fairly good roads to the mines, and nearly 3 tons of mineral can be brought down on a lorry at a time; but carting is costly and slow, and the best method of transport would be to put in aërial ropeways. I believe, however, that there are motor-lorries now in use that would also do this work satisfactorily.

The barytes found at the Dufton and Threlkeld Mines is generally of a better colour than that at Silverband, and is frequently found in " flats," or deposits of varying thickness. These " flats " are generally of the crystalline or glassy variety, and contain some very large crystals and pieces of crystal. The largest known crystal was found here, and weighed about a hundredweight. It is now at the Museum of Practical Geology, London. I found one about two-thirds this weight, and it is now in the Manchester University Museum.

Coal is found in several places on these Fells, but is very poor and thin, and was only used for burning lime and at the mine shops and works.

Still farther south are the Scoredale Mines, which are worked by the Scoredale Barytes Company, Limited. These mines were originally worked for lead, and records are in existence showing that they were in operation more than 500 years ago. Most of the lead appears to be exhausted, and the production of barytes is small. A considerable quantity of fluorspar is found in the mines, most of which is amber coloured and in large crystals. I have seen some very fine specimens. Quartz and other minerals are also found in the flats and veins. The company have a complete mill for grinding barytes, driven by a water-turbine, and have been producing finished barytes for many years.

The next property is on Long Fell and Hilton Fell, and is worked by the Long Fell Barytes Company, Limited, at an altitude of about 2,000 feet. The barytes veins, of which seven or eight have been proved, are in the Melmerby or Great Scar Limestone. Most of them crop out on the surface, and are easily traced for hundreds of yards. The quality of the barytes found here is very good, and yields on analysis over 99 per cent. of barium sulphate. So far no lead or other deleterious mineral has been found in any of the veins. The ore is carried down from the mines to the mill, which is situated at Hayber Lane at the foot of the Fell, by means of a single-rope aërial ropeway about 2,700 yards long. Owing to the difficulty of obtaining an easement, an angle-station had to be put in; but in spite of this the plant has worked satisfactorily.

The mill at Hayber Lane is a recently-erected stone building. Power is supplied by a 75-horsepower suction-gas plant, which works very well and gives little trouble. The plant is well laid out to minimize the handling, and room is left in the buildings for an extension of the grinding machinery.

Mining.—The usual methods of working barytes are: (1) by surface working, which consists of simply quarrying out the vein, and (2) by driving levels in the veins and stoping down the material above. In driving the level, which is heavily timbered, "hoppers" or shoots are left in the side of the level through the roof at intervals of about 4 fathoms. The hopper is provided with a slide door for drawing out the barytes. The ore is then stoped in about 4-fathom lengths and left lying on the timber, the surplus material being sent down the hoppers and taken away in wagons, so as to leave room for the miner to work. This process is repeated until sufficient height is reached, and the broken ore can then be drawn off through the hoppers as required.

Manufacture.—The barytes as sent from the mine is first washed and sorted while being raked over the "washing-grid," which is a short set of bars with a stream of water playing on from a perforated pipe placed over the bars. This operation washes away the clay; all the finer barytes goes through the grid, and is caught in a trough, from which it is elevated into trommels, which separates it into different sizes, and it is then passed into the "jiggers."

The rough barytes is passed through a stone-breaker and broken down to about the size of hazel nuts; it is then passed through the trommels and "jiggers," which remove any limestone or foreign material. It is bleached in lead-lined vats, each holding about 5 tons. Sulphuric acid is poured in the vat over the barytes, and the contents made to boil by passing steam through for several hours. When sufficiently bleached, the acid is run off, the barytes is washed quite free from acid, and it is then wheeled to the drying kiln and dried on heated flues. It is now ready for grinding, which is effected either by passing it through a

ball-mill or crushing rollers and then through mill-stones. These are of French burr and usually about 4 feet in diameter, and to obtain the finest quality it should pass through at least one pair of " kibbling "-stones, and two pairs of finishing-stones. The barytes is then ready for bagging and sending away.

Uses.—The fine-quality ground barytes has many uses, namely, for making paints and white enamels, in rubber manufacture, for coating wall-papers, filling for cloth, photographic papers, etc., and according to the Government reports was largely mixed with Austrian flour, for which purpose it would certainly add weight!

The coloured mineral is used for paints and other purposes where a pure white is not necessary. The common qualities are used in the manufacture of barium salts, lithophone, boiler-compositions, etc.

There are large quantities of very good limestone on most of the Fells, but, owing to the cost of transport, this has only been used for local purposes, being burnt or ground fine for land-dressing. I understand that an area has been recently acquired by a large iron company who intend to connect it to the railway and to quarry several thousands of tons of limestone per week.

There are also good deposits of gypsum (sulphate of lime) near Kirby Thore. These are being worked and made into plaster-of-Paris.

On the west side of the chain of Fells is a large intrusive dyke, which brings up the shales and lower measures and forms a series of pikes or hills. The east side of this dyke is composed of quartz and conglomerates, which crop out boldly at the top of Brownber Hill. I have carefully examined many specimens of the quartz, some of which are highly coloured, and from their appearance I think it very probable that they will be ore-bearing in depth, and quite possibly may contain some of the rarer metals.

Prof. Sir William Boyd Dawkins (Manchester University): It is a matter of interest that we should know something about that great line of fault or dyke. Is there any barytes in it; or does the fault or dyke shut off the barytes on the north from the area on the south in which the barytes is found?

Mr. Vincent Bramall (West Didsbury): The fault encloses all the limestone and minerals, and, moreover, brings up the shales. There is no barytes in the dyke itself; it is nothing but a mass of quartz. The conglomerate is brought up at the side of it.

Prof. Sir William Boyd Dawkins: That shows that after these lodes were impregnated with mineral matter this line of fault cut off the area to the south. Barytes is found much nearer Manchester than some of us realize—for example, no further away than Alderley. It occurs in red sandstone, the grains of which are cemented together by the barytes.

Mr. H. O. Dixon (Westhoughton): The only local occurrence of barytes of which I know is that between Rivington and Anglezark, where there are some old mines which were worked in 1820 by Germans. Baines states in his history of Lancashire that they were the first mines in the county at which barytes was worked, and they are, or portions of them are, still to be seen. Is there any blend in connexion with the galena found in the deposits?

Mr. Bramall: No; there is no blend. There is some on the other side of the Fells, but not in the districts with which I have dealt.

Mr. F. N. Siddall (Atherton): The largest barytes mine in the kingdom is, I believe, at a colliery in the North of England, where the mineral was found on crossing a fault or dyke. I have visited several barytes mines in Ireland, the chief of which are in the south, near Dunmanos Bay. In every case the method of working is by overhand stoping, as described by Mr. Bramall, and in almost every instance the mines are situated in the most inaccessible places.

Mr. Bramall: The big dyke crops up in a hill which has a slope of about 45 degrees, and the dyke appears to be nearly vertical. On the other side of the dyke are the lower shales. So far, I have not found anything on this side but grits and shales; there is not a trace of metallic ore. There is no barytes, and the limestones are cut off entirely. It is presumed that there is a hidden coalfield in the Vale of Eden, and at a little pit near Colby coal has been worked, but I have not been able to obtain any information regarding it.

Mr. Siddall mentioned a mine in the North of England where barytes was found. This is Brancepeth Colliery, which has only recently stopped working the barytes that occurred in a large fault. The mine was one of the most productive in the country, but owing to the high wage cost it had to be closed down. The output at Dunmanos was one of the largest in Ireland, where a very pure white barytes was produced, but it has also had to be closed down. A large amount of barytes is produced in Shropshire, but most of it is of a bad colour. A considerable amount is worked in Derbyshire, but fluorspar is mixed with the barytes, and it has not been possible to separate it satisfactorily.

The mine with which I am now concerned has been closed for fifteen or twenty years. It was worked for barytes for a time; but the owner found that it paid him better to ship barytes from Spain and have it ground here than to mine it in his district.

THE SOUTH STAFFORDSHIRE AND WARWICKSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING,

HELD AT THE UNIVERSITY OF BIRMINGHAM, EDMUND STREET, BIRMINGHAM, APRIL 1ST, 1921.

MR. J. R. FELTON, PRESIDENT, IN THE CHAIR.

THE LAW OF SUPPORT.*

BY DAVID BOWEN, BARRISTER-AT-LAW.

I.—INTRODUCTORY.

This subject is one of considerable importance to the mine-owner and mining engineer. There is perhaps no question so intimately connected with the work of the miner, and which so materially affects mining operations, as the necessity for providing support and the prevention or regulation of subsidence of the strata overlying the particular seam being worked. The economical exploitation of the minerals and the support of the superincumbent strata are the two main determining factors in the choice of the method of working; and this fact comes into greater prominence in view of the new complications incident to mining at greater depths.

Surface land or an underground seam in its natural state enjoys vertical or subjacent support from the soil or strata below, and lateral or adjacent support from the adjoining soil or strata. If the land which receives and the land which affords support form separate tenements, the owner of the former may be entitled to a right of support as against the owner of the latter; that is to say, the one has a right in law to have his land supported independently of anything which the other may do in his own land in the exercise of his proprietary rights.

This right of support may be natural or acquired. The natural right is that which is incident to land unincumbered by buildings and in its natural state. The acquired right comprises the right to the increased measure of support required to sustain the weight of buildings, or the modified measure of support required by works such as railways, canals, or waterworks, or even by land the natural stability of which has been diminished by excavation either within the land itself or in the neighbourhood. The natural right is so-called because it is a natural right incident to the right of property in the land; it is a right of property analogous to the right of a riparian owner to the flow of a natural stream; it does not originate in grant. The artificial right, as it is sometimes called, is acquired by grant or under some of the presumptions which in law supply the place of grant. But although the rights thus differ in their origin, their character is in each case the same: the acquired right is inseparable from, and, as between the parties to the instrument of severance, is a mere enlargement of the natural right.

* This paper has also been read and discussed by the South Wales Institute of Engineers, and is published in their *Proceedings*, 1921, vol. xxxvii., No. 2.

The right to support of a surface-owner as against a mineral-owner imposes upon the latter an obligation not to injure his neighbours' property by subsidence. But the obligation does not confer upon the surface-owner a right to have the minerals retained *in situ* for his protection. The mineral-owner is entitled to enjoy his minerals according to their natural mode of user, so long as he does not infringe the maxim *sic utere tuo ut alienum non lædas* ("So use your own property as not to injure that of your neighbour"). The getting of minerals without negligence and in a proper course of working is not an unlawful act; accordingly the mineral-owner may dig into or even remove the whole of the minerals if the soil above does not fall. The obligation to support may be fulfilled by the substitution of artificial support.

The right of support to the surface upon the minerals is independent of the nature of the strata, or the difficulty of propping up the surface, or the comparative value of the surface and the minerals. Therefore there is no such thing as a right to a *reasonable* support for the surface. It is impossible to measure out degrees to which the right may extend, for there is no standard by which the reasonableness of the support from underlying strata can be gauged. The only reasonable support is that which will protect the surface from subsidence and keep it securely at its ancient and natural level.

It follows that the surface-owner's right is not modified by the fact that the obligation not to cause damage by subsidence renders the effectual working of the mines impossible; this may happen in the case of coal-mines from the extent of pillars required for support, or in the case of metalliferous mines owing to the irregular distribution of the ore making it impossible to calculate and set out pillars. There is likewise no modification of the surface-owner's right if the supported land contains strata of an unstable nature which escape and cause subsidence if the adjoining owner excavates his land. Instances occur in the case of pitch, which becomes soft and oozes out when exposed to the atmosphere; and in the case of running silt.

It has been questioned whether the degree of support for underground strata is the same as for the surface, and opinion on this point appears to be somewhat divided. One school holds that the reasons for inferring an absolute right of support for the surface apply with equal force in the case of the upper of two seams. The other school doubts whether this reasoning applies without some modification, on the ground that the effect of withdrawing support is or may be very different in the two cases. Subsidence of the surface may mean ruin; subsidence of an upper seam may result only in increased expense in working it.

The presumption that the surface-owner has a right to support for his land may, of course, be rebutted by evidence to the contrary. If there is no instrument defining the respective rights of the surface-owner and the owner of the subjacent or adjacent land, the presumption will, in general, be absolute. It may in some cases be rebutted by evidence of a right by custom or prescription to work the minerals without leaving support. Generally, however, if a right to withdraw support exists, the power to do so has been conferred upon the mineral-owner by the instrument of severance.

The presumption is independent of the manner of severance. It applies equally whether severance has been effected by a grant of mines and minerals apart from the land, or by a grant of the land with an exception of the minerals. The form of the instrument is immaterial; it may be a grant in *fee simple*; or it may be a lease for a term of years;

or it may be an Inclosure Act, or an Award. So strong is the presumption in favour of the surface-owner that a right of working the minerals so as to withdraw support will be inferred only if the language of the instrument, either by express words or by necessary implication, unequivocally conveys that intention.

The artificial right of support is not an incident, but is a distinct right of property which can be acquired only by grant or by some means equivalent in law to grant. It may be acquired by grant, express or implied, or under the doctrine of prescription, and when acquired it is, in general, an enhancement or enlargement of the natural right.

A right of support for artificial structures is frequently created by statute, as where railway companies, canal companies, and other like undertakers are empowered to construct and maintain works of public utility in the lands of private owners. The general rule on this head of law is that where the legislature gives power to a public body to do anything of a public character, the legislature means also to give to the public body all rights without which the power would become wholly ineffective. Accordingly, if support from subjacent mines is necessary, the grant of a right of support will be presumed unless the provisions of the statute negative the inference.

An express grant or reservation of the artificial right to support is not of frequent occurrence; but the same object is often attained, in mining leases, by inserting a covenant which binds the lessee not to work a certain area, or to leave specified pillars for the support of buildings. The restriction thus imposed differs from a right to support, being more extensive in some respects and less so in others. Where a mere right to support exists, the mineral-owner may work all the minerals, provided that he substitutes adequate artificial support. But where a restriction is imposed by covenant, the lessee is prohibited from working or getting the minerals within the specified area, irrespective of whether it is more or less than is in fact required for the support of the buildings, and whether or not substituted support is supplied by artificial means. Sometimes the requisite pillars are excepted from the demise.

A right of support for buildings arises much more frequently under the doctrine of implied grant than by express grant. It differs from a fetter imposed upon the working of mines in that it does not prohibit working within any area; the mine-owner, as in the case of the natural right, is free to work in a usual and proper manner, provided that he substitutes artificial support.

The right of support for buildings from subjacent or adjacent soil may be acquired by prescription where it has been enjoyed from time immemorial, or under the presumptions which, in law, supply the place of prescription when length of enjoyment has been less than immemorial.

II.—Right to Withdraw Support.

A right to work mines so as to let down the surface is capable of grant. No particular words are necessary; they may take the form of a covenant, but if they are susceptible of interpretation as a grant, the grant is valid. Such a grant does not operate as a release of the right to support which exists *ex jure naturæ*; it operates as a grant of a right in the nature of an easement over the surface. The right may be created by the instrument of severance or by a separate and independent instrument. A power to withdraw vertical support does not confer upon the mine-owner who also owns the lateral mines the right to withdraw lateral support.

The right to withdraw support may be conferred upon the mine-owner by express words; but more frequently it arises by implication. Where the words are not express, the right will be inferred only if the language of the instrument either in itself, or interpreted in the light of admissible evidence as to the circumstances of the case at the time when the transaction was entered into, unequivocally conveys the intention to confer a power to withdraw support.

III.—Construction of Instruments.

There are two main presumptions which govern the construction of mining instruments with regard to support: (*a*) it is to be presumed that the surface-owner intended to reserve the right of support for the surface; (*b*) it is also to be presumed that the minerals are to be enjoyed. That the first of these is the ruling presumption has been established in a series of decisions culminating in that of the Butterknowle Colliery Company *v.* Bishop Auckland Industrial Co-operative Society (1906, A.C. 305). These cases relate to support from coal-seams, and underlying them all is an assumption that working in a commercial sense is possible notwithstanding the obligation to leave support, so that effect can still be given to the second presumption. In many cases the assumption is contrary to fact; and it was not till the case of Butterley Company *v.* New Hucknall Colliery Company (1909, 1 Ch. 37; 1910, A.C. 381) that the impossibility—to the knowledge of the parties at the date of the instrument of severance—of working at all without causing subsidence was by proper evidence brought before the court. The result is to increase the weight of the presumption in favour of the mine-owner in cases where that evidence is available.

The evidence in the Butterley case went to prove that subsidence inevitably follows the working of minerals in seams except at shallow depths, and that this subsidence is independent of the method of extraction adopted, although differences in method of extraction may produce differences in the evenness and regularity of the subsidence. In the case of Welldon *v.* Butterley Company (1920, 1 Ch. 130) the evidence went to prove that no exception could be made of shallow seams; that subsidence inevitably occurs whatever the depth of the mineral excavation. A passage in the decision that "there is no method by which coal can be so worked as not to cause subsidence" would appear to need some qualification. It is undoubtedly true that in old times methods of working were practised by which the greater proportion of the coal was abandoned in the form of pillars in order to support the roof, and subsidence was avoided. It is perhaps true that under the changed conditions of modern times it is impossible to work profitably any seam of coal by a method which would leave intact about 70 per cent. of the mineral, and that the passage in the decision in Welldon *v.* Butterley Company is accurate on that assumption. On this point it is important to remember that each decision is a decision on the facts of the particular case in question, and cannot be applied without question to other cases.

The propositions which had been established up to the time of the case of the Butterknowle Colliery Company *v.* Bishop Auckland Industrial Co-operative Society are stated in that case by Lord Loreburn in the following terms:—

"Whenever the minerals belong to one person and the surface to another, the law presumes that the surface-owner has a right to support, unless the language of the instrument regulating their rights, or other evidence, clearly

shows the contrary. In order to exclude a right of support, the language used must unequivocally convey that intention, either by express words or by necessary implication. For the same presumption in favour of a right of support which regulates the rights of parties in the absence of an instrument defining them will apply also in construing the instrument when it is produced. If the introduction of a clause to the effect that the mines must be worked so as not to let down the surface would not create an inconsistency with the actual clauses of the instrument, then it means that the surface cannot be let down."

In construing any instrument, therefore, if there are no express words reserving the right to support or granting the power to let down the surface, the test to be applied is this: Apply to the instrument a clause to the effect that the mines must be worked so as not to let down the surface; if this clause is inconsistent with the actual clauses of the instrument, then power to let down the surface will be implied; if there is no such inconsistency, then power to let down the surface will not be implied.

In the same case Lord Macnaghten said:—

"The result seems to be that in all cases where there has been a severance in title and the upper and lower strata are in different hands, the surface-owner is entitled of common right to support for his property in its natural condition without interference or disturbance by or in consequence of mining operations, unless such interference or disturbance is authorized by the instrument of severance either in express terms or by necessary implication."

And Lord Davey said:—

"It cannot now be disputed that *prima facie* where the surface is in one owner and the minerals in another the latter cannot work the minerals so as to destroy the surface."

Lord Loreburn continued:—

"Illustrations are numerous in the reports. Words, however wide, that merely authorize the getting of all the minerals have been held not to authorize so getting them as to let down the surface. Where power is given to get the minerals on paying compensation for damage done to the surface, the court will still scrutinize the compensation clause. Are there any rights belonging to the mine-owner on the surface (such as a right of making roads) to which the compensation clause may refer? If the compensation clause is capable of being satisfied by reference to acts done *on* the surface, then, though it may be wide enough to cover also damage done *to* the surface by taking away the support; still it must be confined to damage done *on* the surface, and the inference that support may be taken away on payment of compensation will not be drawn. Again, courts have asked whether the compensation is manifestly inadequate for such an injury as letting down the surface and have commented upon the absence of any provision for compensation. Either of these circumstances has supplied judges with a reason for so cutting down wide language in a grant of minerals as to imply a condition that the surface shall be supported. The process of reasoning in such cases seems to be that parties must not be supposed to have intended what would be unreasonable, and unjust. I think that in each of them a clause providing for a continuance of support would not have been inconsistent with the actual clauses."

In these statements the Butterknowle case summarizes in an authoritative manner the results of previous decisions, notably Davis *v.* Treharne (1881, 6 A.C. 460); Dixon *v.* White (1883, 8 A.C. 833); Love *v.* Bell (1884, 9 A.C. 286); and New Sharlston Collieries *v.* Westmorland (1900, 1904, 2 Ch. 443n.) in the House of Lords. On the assumption of the possibility of working without causing subsidence, they lay down an authoritative rule of construction, namely, that general powers of working are not sufficient *per se* to exclude the right of support.

In the Butterley case the question under consideration was the support of an upper seam by an underlying seam, but the case was decided on principles which apply equally well and have since been applied to support of the surface (see Locker-Lampson *v.* Staveley Coal & Iron Company (1909, 25 T.L.R. 136); Jones *v.* Consolidated Anthracite Collieries (1916, 1 K.B. 123); Bank of Scotland *v.* Stewart (1891, 18 Ct. of Sess. Cas. 4th S. 957); Anderson *v.* M'Cracken Brothers (1900, 2, *ibid.*; 5th Ser. 780). The evidence was clear that the law of inevitable subsidence was known to the parties at all material times. The instrument of severance showed an intention that the underlying coal should be worked; it was, therefore, a necessary implication that subsidence was contemplated. In these circumstances, qualification of the powers of working in a mining instrument means no working at all, and would stultify the intention of the parties: the qualification would, in fact, render the instrument inoperative.

The case is thus distinguished from the Butterknowle case and others of that type. On the assumption thus made, the qualification of the general powers of working did not render the instrument inoperative; working was still possible and effect could be given to the intention of the parties, having regard to the interests of both. But there is another distinguishing feature. Support for the surface is so important that judges have spoken of the withdrawal of support as amounting to destruction of property in the surface. In the Butterley case, however, it was shown that the withdrawal of support would result only in subsidence with a slight increase in the cost of working. In these circumstances it was easier to make the inference of a right to withdraw support.

The presumption in favour of the surface-owner is not affected by the nature of the instrument of severance. It holds good whether it be a lease, a deed of grant, or of reservation, or an Inclosure Act, or an Award.

It is well settled therefore that the mere fact of giving very wide general powers to sink pits and to work, get, and carry away minerals does not of itself establish a right to get rid of the common-law right of the surface-owner to have his surface undisturbed. Something more must be found from which the necessary implication may be made.

(*a*) The necessary implication may be made from the reservation of powers which existed before the severance. In Beard *v.* Moira Colliery Company (1915, 1 Ch. 257) lands were granted by an owner in *fee* in 1829. The conveyance excepted all the mines and minerals under the land granted and reserved full and free liberty to enter upon the land, to sink pits and shafts, and to exercise all other powers of working and getting the minerals "in as full and ample a way as if these presents had not been made and executed." There was also provision for payment by the grantor of compensation for damage or injury done in the exercise of the reserved powers. Here there was a necessary implication from the language used that the grantor should have a right to let down the surface if he was to be able to work and carry away the coal in as full and ample a manner as before conveyance. The grantor, being owner in *fee*, if he had not made and executed the conveyance, would have had a perfect right to let down the surface while working the mines, and unless after the conveyance he retained that right he would not have been able to work and carry away in as full and ample a way and manner as before the conveyance.

This decision of the Court of Appeal set at rest a point which had

been in doubt with regard to Chamber Colliery Company *v.* Twyerould (1915, 1 Ch. 268 n.). In that case, Lord Watson, in delivering the judgment of the House of Lords, treated it as a question of some nicety whether similar words were sufficient to oust the common-law right. Admitting that the words were capable of that meaning, he found other provisions of the instrument which in conjunction with these words he held to exclude the right of support. With reference to this case, Lord Halsbury in the New Sharlston case expressed an opinion in favour of the view that the words in themselves were sufficient to " carry you the whole way."

In these judgments the Court of Appeal also refused to apply to the interpretation of such words the rule that has been adopted in the interpretation of similar words in cases upon Inclosure Acts importing that the Lord of the Manor shall enjoy his property as freely as if the Act in question had not been passed. Such words have been treated practically as a dead letter. The rule has been explained as resting upon the change in the nature of the commoner's interest by the Inclosure Act; and there is no ground for extending it to the construction of deeds, where ordinary words ought to be given their plain and ordinary meaning.

(*b*) The necessary implication may also be made where there is evidence from which it can be inferred that the parties have entered into the contract with the knowledge that it was impossible to work without causing subsidence. Such knowledge may, of course, be admitted or proved, but more generally it will be a matter of inference from evidence of mining practice at the date of the instrument. Whether such evidence is available will depend on the date of the instrument; but the law of inevitable subsidence has been known to mining engineers for many years, and this principle probably applies to most modern mining instruments.

In the case of the Butterley Company *v.* New Hucknall Colliery Company, there were five leases, beginning in 1887, of an upper seam of coal. The leases reserved power to work underlying seams with various privileges over the works of the upper lessees; there were also obligations upon the upper lessees not to interfere with the working of the lower seams, and it was thus clear that the parties contemplated that the lower seams should be worked during the currency of the upper leases. It was proved or admitted that the usual system of working in the neighbourhood was by longwall, and that this system was the best and most profitable. It was also proved that it was impossible to work at all without causing subsidence. There was no dispute that these facts were within the knowledge of the parties at the date of the leases. It was further shown that the working of the lower seam concurrently with the upper would not result in the destruction of the upper seam, but would only cause subsidence and slightly increase the cost of working. In those circumstances, working without causing subsidence meant no working at all, to the knowledge of the parties; there was therefore by necessary implication a right to let down, otherwise the intention of the parties that the lower seam should be worked concurrently with the upper would be stultified: the right to work would, in fact, be inoperative.

The same principles were later applied in respect of the withdrawal of support from the surface in the case of Locker-Lampson *v.* Staveley Coal & Iron Company (1909, 25 T.L.R. 136). By a lease dated July 25th, 1871, certain seams of coal under lands in Derbyshire and Yorkshire were demised to the defendants. The lease contained covenants to

work the collieries in a proper and workmanlike manner, and according to the best and most improved methods, until the seam of coal should be exhausted; to leave ribs and pillars of coal for the support of the shafts and buildings of the mine; to leave sufficient coal for the support of houses and buildings on the surface; and to pay to the lessor and his tenants compensation for any damage done by carrying on the mining operations. The defendants and their sub-lessees in a proper course of working worked on the longwall system, and caused a subsidence of the surface. In 1871 the longwall system was the universal method of working in the district, which fact must have been known to the parties and their agents at the date of the lease. It was held that the lessees were entitled to work so as to withdraw support from the surface.

Another instance occurs in relation to a lease of mines in Wales in the case of Jones *v.* Consolidated Anthracite Collieries (1916, 1 K.B. 123). In 1896 the owner of land granted a lease of coal under certain land, with power to sink pits and work. The lessee covenanted to win and work the mines regularly and according to the best and most approved mode of working similar mines in the district. It was proved that for the last fifty years the collieries in the district had worked on the longwall system; that under this system the surface necessarily and inevitably subsided as the result of the working; that a similar result followed under the pillar-and-stall system of working; and that this fact had been common knowledge for at least forty years. It was found as a fact that at the date of the lease the parties knew that the seam could not be worked on the system universally used in the district, or indeed on any other system, without some subsidence. There was, therefore, following the Butterley case, a power to let down the surface; the principle of that case being that a man who has granted a right to work a mine must be taken to allow its being worked in the only way in which it can be worked whatever the effect on his other property may be.

In the case of Buchanan *v.* Andrew (1873, L.R. 2 Sc. & D. 286), a lease of lands was granted, excepting the mines, and the contract provided that the superior should not be liable for any damage which might happen to the land or buildings thereon, by the working of the minerals under the same, or in the neighbourhood thereof, under the longwall system or otherwise; it was conceded that subsidence was inevitable, and it was accordingly held that a power to let down was implied.

The Butterley case seems to affect the meaning to be attached to covenants to work. With reference to the lease of the upper seam in that case, Lord Atkinson said that when the lessees covenant, as they do, that they will during the term of the lease "use and work the said seams, veins, and mines of coal and substances hereby granted and demised, fairly and regularly according to the best and most improved methods now being or hereafter to be in use, and in a workmanlike manner in all respects," it is scarcely possible, in the face of the evidence, to suppose that it was not intended to authorize, if indeed not enjoin, the lessees to work the mines on the longwall system.

With this may be contrasted the remarks of Lord Hatherley, when Vice-Chancellor, with reference to a similar covenant in the case of Shafto *v.* Johnson (1863 8 B. & S. 252n. at page 256). In the district in question the usual mode of working was by pillar-and-stall, and it was the practice to work away the pillars. He considered that a covenant to work according to the best and most approved method of working collieries of a like nature in the district meant only the best and most

approved method of working which would be consistent with the other terms and provisions of the lease and the other legal rights of the parties. If the lease conferred a right to work the pillars, the covenant bound the lessee to do so by the most approved method, but the covenant did not of itself give him the right to work the pillars.

A similar idea underlies the remarks of Lord Selborne in Buchanan *v.* Andrew and Davis *v.* Treharne. In the latter case he considered that a covenant to work in " the most usual and approved way of working " in the county, related to the manner of working the mine for mining purposes; the words did not affect the collateral obligation to afford support. There could not possibly be any local custom in such a district to disregard the right of a surface-owner who was not lessor of the mines; and there was no difference in the position if the surface-owner was also lessor.

In a lease there may be imposed upon the lessee an obligation to perform certain acts which are plainly inconsistent with supporting the surface. Thus in the case of Shafto *v.* Johnson there was a covenant to work " so as to produce the greatest quantity of merchantable coals from out of each and every the workable seams," coupled with provisions for the safety of the mine. Lord Hatherley considered that so far the intent of the lessor was that the lessee should get the greatest quantity of coal without damage to the mine, still reserving his general right to have the surface supported. At most there was an indication that the parties contemplated a power to let down. There were, however, further provisions, including the prohibition of working under a certain area, the object of which was to create absolute protection for that part. When the two classes of covenants were coupled together, the necessary inference followed that there was an intention that all the coal that could be got without damage to the mine should be got; provided always that certain specified property, and that alone, should be protected and supported. When a large part was protected, the inference was irresistible that the part not specifically protected might be let down.

The protection of a specific area by the absolute prohibition of the working of minerals thereunder is not, however, inconsistent with the continuance of the common-law right of support outside that area. Thus in Dugdale *v.* Robertson (1857, 3 K. & J. 695), there was a lease of the mines under 514 acres of land, with full powers to work, except in or upon any demesne lands and pleasure-grounds belonging to and occupied with the mansion, covering 4 acres. It was held that working was absolutely prohibited within the 4 acres, and that no right was granted to work outside that area so as to withdraw support from such land and buildings.

On the other hand, as has been seen in the case of Shafto *v.* Johnson, if there is anything in the words of the working powers to suggest a right to let down, the protection of a specific part of the surface may strengthen the inference of a right to withdraw support from the remainder. So in the case of Chamber Colliery Company *v.* Twyerould, where mines were granted, with power to work as the grantor " could or might have done in case these presents had not been made," it was considered that the inference of a right to let down which the words in parenthesis were capable of bearing, was strengthened by a provision which excepted from the grant the coal under certain buildings and yards. The provision was not *per se* conclusive; but it did indicate an apprehension on the part of the grantors that, but for the reservation, their existing buildings would be exposed to serious risk of injury in the course of working contemplated. It was a precaution absolutely neces-

sary for the protection of these buildings from injury if their grantees had power to work out the whole of the minerals. If the grantees were under an obligation to leave sufficient mineral to support the surface, there was no imperative, if any, necessity for it.

In the case of Brewer *v.* Rhymney Iron Company (1910, 1 Ch. 766), the question arose as to the nature of protection to buildings under a covenant not to injure or endanger buildings, in leases which did not prohibit working under buildings but authorized working according to the most improved system in the neighbourhood, and also bound the lessees by covenant to work according to the best mode of working for the time being adopted in the neighbourhood, and so that all the marketable coal therein capable of being got according to the custom of working in the neighbourhood might be fairly and properly worked. There was also a provision for compensation for surface damage. The method in general use in the district was the longwall system, or a modification thereof. It was held that the lessees had a right as against the lessors to extract coal so as to let down the surface, provided that they made compensation for surface damage, and did not injure or endanger buildings on the surface. The leases could not be construed as conferring the right to let down the buildings doing no unnecessary damage, for this would be, in effect, to ignore the special covenant as to buildings and leave them in precisely the same position as the general surface.

IV.—Compensation Clauses in Instruments.

Where the power of getting the minerals is made subject to the payment of compensation for surface damage, the scope of the compensation clause may, in the absence of evidence as to inevitable subsidence, be material in considering the extent of the working powers granted or reserved.

It is not the function, and presumably it is not the intention, of a compensation clause to define or extend the powers of working; and, in fact, a clause providing that the mine-owner shall make compensation for damage to the surface does not itself afford a strong argument for saying that he may destroy the surface, as there may be other injury to the surface in connexion with the working of the minerals to which the clause will be applicable.

It is not enough then to rebut the presumption of support that compensation is provided in measure adequate or more than adequate to cover any damage likely to be occasioned by the exercise of the powers and privileges granted or reserved by the instrument of severance. The court will consider whether there are any rights belonging to the mine-owner on the surface (such as the right of making roads, making spoil-banks, etc.) to which the compensation clause is capable of being satisfied by reference to acts done *on* the surface; then, though it may be wide enough to cover also damage done *to* the surface by taking away the support, still it must be confined to damage done *on* the surface, and the inference that support may be taken away on payment of compensation will not be drawn.

But even if the provision for compensation is general and is wide enough to cover damage by subsidence, it may provide only a cumulative remedy in covenant for the wrongful withdrawal of support, if injury is in fact caused; or it may apply to damage arising from accident or negligence in the exercise of the powers of working.

It may be, however, that no surface powers are exercisable to which the provisions for compensation can refer: it may then be possible to refer the compensation clause only to injury from subsidence, or the clause may

specifically refer to injury by subsidence. In such case it is a reasonable if not a necessary inference that subsidence is authorized. As Lord Blackburn said in Davis v. Treharne, the conclusion is very strong from such facts that the lessor has authorized letting down the surface.

It is not clear how far these principles are reconcilable with later *dicta*. In New Sharlston Collieries *v.* Westmorland Lord Davey said :—

"Speaking for myself, I cannot see why a covenant providing a particular measure or mode of compensation is in any way inconsistent with the existence of an obligation not to let down the surface, even though that covenant extends beyond the surface, and is applicable also or even exclusively, to underground operations. The use of the words 'by reason of the exercise of the powers' does not seem to me to carry it any further, because it may apply to any incidental injury done—whether accidentally or wilfully makes no difference—whilst exercising the powers. It does not seem to me to give a licence to do the injury if you say that a person shall pay compensation if he does it. A covenant to pay compensation for doing a thing which you are prohibited from doing is in no way contrary to or inconsistent with the continuance of the obligation not to do it. Therefore I do not accede to the argument that the existence of a covenant for payment of compensation for letting down the surface is, whether it applies wholly or partially to underground operations or not, in any way inconsistent with the continuance of the common-law obligation."

These remarks were subsequently explained by Lord Davey in the Butterknowle case. He there stated that he did not intend to say more than what he understood Lord Blackburn to have meant in Davis *v.* Treharne. "If the words mean that the owner of the coal may take away the whole coal regardless of the consequences, on making compensation for the injury done, the law will give effect to such a bargain or enactment"; but a general compensation clause does not itself afford a strong argument that the miner may destroy the surface. It would appear, therefore, to be the meaning that a clause specifically dealing with compensation for damage by subsidence, in conjunction with other provisions, may lead to an inference that subsidence was contemplated.

Although provision for compensation is not of itself sufficient to show that the mine-owner working in the usual and proper manner is at liberty to let down the surface, the absence of any provision for compensation is some indication that the ordinary rights of the surface-owner were intended to be left untouched. On the other hand, the presence of a provision for compensation which is obviously inadequate, or plainly inappropriate if applied to damage by subsidence, is cogent evidence to prove that subsidence was not contemplated.

The principles stated above are illustrated by the decisions in Harris *v.* Ryding (1839, 5 M. & W. 60); Smart *v.* Morton (1855, 5 E. & B. 30); Davis *v.* Treharne (1881, 6 App. Cas. 460); Dixon *v.* White (1883, 8 App. Cas. 833); Sitwell *v.* Londesborough (1905, 1 Ch. 460); Smith *v.* Darby (1873, 7 Q.B. 716); Aspden *v.* Seddon (1875, 10 Ch. App. 394); Chamber Colliery Company *v.* Twyerould (H.L. July 20th, 1893, not reported); New Sharlston Collieries *v.* Westmorland (1904, 2 Ch. 443, 446); and Williams *v.* Bagnall (1867, 15 W.R. 272).

V.—Inclosure Acts.

Before inclosure, the lord is entitled *prima facie* to work the minerals in the waste of the manor; unless his rights are restricted by custom, the only limitation upon his powers of working is that imposed by his liability to leave a sufficiency of common for the commoners. But after inclosure, the position is changed. An Inclosure Act is really nothing more than an

agreement between the parties sanctioned by the legislature. Before the Act, the land down to the centre of the earth belongs to the lord; he agrees to the Act, and if the minerals are excepted, he places the allottee of the surface of the enclosed waste in the same position as if it had been ancient inclosed land and the lord had alienated the surface reserving the minerals. The allottee acquires a right of support unless otherwise provided, and *prima facie* the owner of the minerals must work them in a way so as not to damage the extended interest which the commoner has acquired under the Act. The principles which govern the construction of a common-law grant of land with an exception of mines in questions of support apply accordingly to the construction of Inclosure Acts. It is doubtful, however, whether the effect of deep workings had been accurately ascertained when the private Inclosure Acts of the eighteenth century were passed. The actual decisions upon such Acts would appear, therefore, to be unaffected by the principles laid down in Butterley Company *v.* New Hucknall Colliery Company; but the principle seems, however, to have been recognized in Bell *v.* Dudley (1895, 1 Ch. 182).

As in the case of a common grant, the reservation of powers of working minerals, expressed in general terms, are not sufficient to rebut the presumption in favour of the allottee. Nor is it enough that there are reserved to the lord powers of working as fully and freely as if the Act had not been passed. Such a provision does not mean that the lord can destroy the surface as he would have been able to do when the common was waste land; the provision must be interpreted with regard to the changed interest of the commoners. As Lord Macnaghten said in the Butterknowle case:—

"The difficulty of applying such a hypothesis to the altered condition of things brought about by an Inclosure Act has, it seems to me, led this House to treat the provision in which it was found, and of which it would seem at first sight to be the keynote, as a dead letter for any practical purpose."

But from Lord Halsbury's observations in the Butterley case, if "misled" had been substituted for "led," this observation of Lord Macnaghten would have been more accurate.

Since the principles which apply in considering the effect of a compensation clause in a common grant also determine the effect to be attached to the presence or absence of a means of compensation in an Inclosure Act, it is unnecessary to discuss this question in detail in this paper.

VI.—The Law of Support in Relation to Statutory Undertakings.

"A vendor, on selling part of his property, is presumed to grant such a measure of support from the property he retains as is necessary for the property sold in its then condition, or when applied to the purpose for which the grant was expressly made; but the precise measure of such support depends upon the special circumstances of each case" (see Dart: *Vendors and Purchasers*, Vol. I., page 422). Applying this general principle to the case of statutory undertakings, it follows that the rights of a corporation which acquires lands or erects works thereon in pursuance of statutory powers are the same as would be those of an ordinary individual, except so far as such rights are modified or varied by statute or by contract between the parties (see Caledonian Railway Company *v.* Sprot, 2 Macq., 449; Elliot *v.* North-Eastern Railway Company, 10 H.L. Cas., 333). Apart from cases coming within what is commonly known as "the Mining Code," the principle just enunciated is illustrated by several decisions in cases typical of special railway and canal Acts and similar acts, antecedent to or replacing the Mining Code, and which need no elaboration here.

What is commonly known as " the Mining Code " is a *fasciculus* of clauses contained in the Railways Clauses Consolidation Act, 1845, the Waterworks Clauses Act, 1847, and the Public Health Act, 1845 (Support of Sewers) Amendment Act, 1883. This code contains an absolute prohibition against the working of any minerals within a prescribed distance of any of the works of the statutory undertakers, except under certain conditions which will be stated presently. It has been described as the " charter of the mine-owners' rights " within the prescribed distance, and defines the relations between mine-owners on the one hand and statutory undertakers on the other, where land is compulsorily taken in pursuance of statutory powers.

It will be convenient to summarize the position under this *fasciculus* of clauses in a series of propositions, as follows :—

(1) What is sold to the undertakers is the surface only; they do not acquire any minerals excepting only those as are necessary to be dug or carried away or used in the construction of their works, unless they are expressly purchased.

(2) Minerals lying under the works or within the prescribed distance, if any, may not be worked by the mine-owner until he has given notice of his intention so to work to the undertakers.

(3) If the undertakers are not willing to treat for payment of compensation, the mine-owner may, at the expiration of thirty days after notice given, proceed to work his minerals within the prescribed area.

(4) If the undertakers, on the other hand, are willing to treat for payment of compensation, the mine-owner may not work the minerals compensated for at all; but he may, where his mines lie on both sides of the works, cut and make so many airways, headways, gateways, or water-levels through the mines within the prescribed area, as may be necessary to enable him to ventilate, drain, and work his mines on each or either side of the works.

(5) Up to the moment when the mine-owner desires to work his mines within the prescribed area, the undertakers have every right of subjacent and adjacent support; but from the receipt by them of notice of the intention of the mine-owner to work such mines, the common-law right of support, as far as the minerals within the prescribed area are concerned, is taken away, and the undertakers are left to such support as they may acquire by purchase or by payment of compensation as provided by the code.

I propose to deal with these observations in the order given.

(1) Although the normal procedure is the purchase of the land without the mines, the mines may be included if expressly purchased, and such purchase may be made compulsorily or by agreement. Further, the mines may be purchased at any time, at the option of the undertakers, after the surface has been acquired, provided that such purchase takes place within the period limited for the exercise of their statutory powers. They may purchase the whole of the underlying minerals or a part only, at their option, but their compulsory power may only be exercised as regards the minerals within the prescribed area, and within the prescribed time. At the expiration of that time, they may purchase the minerals within such limits by agreement. It is to be noted that they may only purchase for the purposes of the works they are authorized to construct. It is unnecessary to consider here what meaning is to be attached to the term " minerals " within the code.

(2) When the mine-owner wishes to work the minerals within the prescribed area, he must give notice of his intention to the undertakers.

The notice must be *bona fide*. There must be not only an expression of desire, but an honest actual existence of the desire to work either by himself or by his lessees to justify an owner in giving such a notice. The notice must be given thirty days before the commencement of the working.

(3) If, at the expiration of thirty days from the receipt of notice of intention to work, the undertakers have not given the mine-owner a counter-notice to the effect that they are willing to treat with him as to the compensation to be payable for the minerals left unworked, then the mine-owner is at liberty to work and go on working the minerals, subject to the restrictions imposed by the code. The undertakers are not bound to any fixed period within which they *must* give a counter-notice. If at any time after the receipt of the notice of intention to work they fear damage to their works, they can stop the working of the minerals or the continuance of such working by a counter-notice of their willingness to pay compensation for the minerals which have not been worked, and which they desire to be left unworked. It appears that the undertakers may, if they think fit, give a counter-notice as to part of the minerals at one time, and another part at another time. Where compensation has been made for minerals left unworked, the minerals thus left do not become the property of the undertakers, but remain the property of the mine-owner. The only result is that neither the mine-owner nor the undertakers may remove such minerals. Where the mine-owner is at liberty to work the minerals within the prescribed area, as happens when the undertakers do not give counter-notice to treat for compensation within thirty days of notice of intention to work, working may only be done in a manner proper and necessary for the beneficial working of the minerals, and according to the usual manner of working such mines in the district where the same are situate; and if any damage or obstruction is occasioned to the railway or other works by improper working of such mines, such damage or obstruction must be forthwith repaired or removed, as the case may require, by the mine-owner, or in default thereof the undertakers may make good the damage and recover the expense occasioned thereby from the mine-owner.

(4) The headways, etc., which may be cut and made through minerals within the prescribed area, where compensation has been paid, are limited to the prescribed dimensions, or, where no dimensions are prescribed, to 8 feet in width and 8 feet in height.

Compensation is only claimable in respect of substances which are minerals within the code, and which lie within the prescribed area. This compensation can be claimed only by the person entitled to give notice of intention to work. Such compensation is full compensation—that is, what the minerals would have sold for if worked, less the cost of working them. If the minerals have no value, or are unprofitable to work, there can be no right to compensation.

(5) As to the right to support, it should be remembered that on a conveyance of the surface, excepting the mines, in the absence of any express words to the contrary, it is implied that the surface conveyed is entitled to the common-law right to subjacent and adjacent support. Section 77 of the Railways Clauses Act, 1845, and section 18 of the Waterworks Clauses Act, 1847, however, are, in substance, clauses enacting that a special rule of construction shall apply to conveyances of land to statutory undertakers. They invert the ordinary rule of construction applied to ordinary conveyances as stated above. Either by themselves or in conjunction with the other clauses of the code, where the mines are

not purchased, they have the effect of depriving the undertakers of all rights to support from the excepted mines. The code takes away rights of adjacent and subjacent support to some extent from and after a particular moment. If the mine-owner wants his mines, and is desirous of working them, then the moment arrives; and if the undertakers, upon notice are unwilling to purchase the mines, then the mine-owner may, so far as is necessary for the enjoyment of his own mine, destroy the adjacent and subjacent support (see Ruabon Brick, etc., Company *v.* Great Western Railway Company (1893), 1 Ch. 454, 457, per Bowen, L.J.).

The rights given by section 78 of the Railways Clauses Consolidation Act, 1845, to the railway company are in substitution for the common-law rights of support, whether vertical or lateral, within the 40-yard limit. The general effect of this *fasciculus* of clauses is to establish on a statutory basis the reciprocal rights of the railway company on the one hand, and the owners, lessees, or occupiers of mines lying under or near the railway, on the other. These reciprocal rights are different from, and inconsistent with, the common-law right of vertical and lateral support, and entirely replace those rights as between the railway company and the owners of the mines, so that on the one hand the railway company cannot claim those common-law rights as against the mine-owners, nor can the owners of the mines claim that freedom of working which is compatible with the duties of support, and is, therefore, permitted by the common law. In return for this novel servitude imposed upon them by the legislature, the owners of such mines have sundry rights and privileges granted to them. These rights and privileges are given to them by statute and not by contract, and they are unaffected by any transactions between the railway company and third parties (see London & North-Western Railway Company *v.* Howley Park, etc., Company (1911, 2 Ch. 109, 110, per Cozens-Hardy, M.R., and Fletcher-Moulton, L.J.).

As regards substances which are not under the land purchased, and are inside the prescribed distance and are not minerals, the common-law right, however, remains. As regards all substances, whether minerals or not, outside the prescribed distance, the common-law right also remains. Prior to the decision in London & North-Western Railway Company *v.* Howley Park, etc., Company, the *dicta* on the subject were not uniform, and some of them were obscure. In that case the defendants were lessees of minerals lying outside the prescribed distance, which they held from the successors in title from the vendor to the railway company. It was held that railway companies were entitled to the common-law right of lateral support for their railway from such minerals. It was admitted that outside that distance no statutory notice could be given, and no counter-notice could be given; and it was held that the common-law right was only taken away to the extent to which the notice and counter-notice could relate.

It is impossible within the limits of this paper to discuss in greater detail any of the particular decisions illustrative of the legal position under the Mining Code. What has been stated above is a sufficient general indication of the position, and may be applied broadly to particular cases which may arise.

Mr. JOHN BRINDLEY (Wolverhampton): No reference has been made to the withdrawal of water from pits, although it is generally considered that an accumulation of water in a mine affords support to the surface. I do not know whether any cases have been decided on that point, and I approach the subject merely through an interest in hydraulics and machinery for the removal of water in various ways; but, personally, I consider it a practical impossibility for water to support the overhead strata of a mine. If a mine is waterlogged and all the outlets are plugged up and hermetically sealed, then possibly some support may be given; but if there are outlets at the shafts or elsewhere, there can be no support to the superincumbent strata. I find it difficult to conceive how support is possible, because the rock or other material, being of a greater specific gravity than water, would tend to get to the bottom in any case. It has, however, been frequently stated that the withdrawal of water will let down the surface; and I should like to know whether Mr. Bowen has had to deal with this point in the course of his legal experience.

Another matter is that of compensation for surface damage. I know of at least one case where a local council claimed that it was entitled to compensation for surface damage. One authority whose roads had been let down 20 or 30 feet claimed to have them lifted up to their original level. I believe that considerable litigation resulted, in spite of the fact that the whole area as well as the roads themselves had been let down through the taking out of the coal.

Mr. STOREY: I once lived in a house adjoining a colliery in Lancashire, and it was said that the house had been damaged through the colliery-owner tapping the water from under it, and compensation was paid by the colliery company to the owner of the house. In another Lancashire mine the manager and some workmen were sounding for water, when they made an opening, and the water rushed out in such volume that the workmen were carried away and drowned. The manager escaped with his life by clinging to the roof supports. In this case, the water accumulation must have been a kind of reservoir or loch. It is well known to geologists that there are subterraneous lochs held in suspension, and it is presumed that if the water is tapped away, the surface will be brought down.

Mr. DAVID BOWEN (London): The law of support in regard to mining is about the most complicated subject with which we have to deal in the whole of this specialized branch of the law, and cases are constantly arising in connexion therewith. About three weeks ago I was engaged before the High Court in a case which embodied nearly all the points I have dealt with in my paper.

Reference has been made by Mr. Brindley to the withdrawal of water. It was not part of my purpose to deal with that question—my paper was intended principally as a discussion of the principles generally applicable to the construction of mining instruments. The law as to support by underground water is still, to a certain extent, in doubt. There are, however, many cases arising in which the law of support is connected with water in mines, particularly in connexion with the tapping of water in underground mines. I do not quite agree with Mr. Brindley that where all the outlets are hermetically sealed, and the water has no way of escape, no support is given to the superincumbent strata. Although the strata are of higher specific gravity, yet the water is not

compressible, and the upper strata are bound to be supported, unless there is an outlet. Cases concerning the tapping of water arise simply and solely in the event of water being tapped in such a way that the surface subsides. Until the water is tapped, the surface is supported; when the water is tapped, the surface subsides, and the people concerned begin to complain. Whether the mine-owner in tapping such water is liable for damage by subsidence depends on several circumstances. He may have taken a lease of the mines after the water had accumulated in the workings. In that case, if he had no reason to suspect the presence of the water, but accidentally tapped it, he could not possibly be held liable for subsidence of the surface owing to the escape of water. If, on the other hand, he was responsible for the old workings, and was also liable under the lease for the support of the surface, then the tapping of water and the subsidence of the surface bring upon him liability in damages, except where the presence of the water is due to an accidental circumstance, such as the overflowing of a neighbouring river, and upon the continuance of which the claimant had no right to rely.

With regard to the highways being kept up to their original level, this depends on the particular facts. The general rule is that local authorities have a right of action if damage by subsidence occurs to a highway as a result of mining operations. But it is submitted that if no action is taken by the authorities before danger of subsidence arises, their only remedy afterwards lies in damages in respect of the cost of repairing the highway.

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THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

GENERAL MEETING,

Held at the Danum Hotel, Doncaster, April 2nd, 1921.

Mr. J. H. W. LAVERICK, President, in the Chair.

DEATH OF COL. T. W. H. MITCHELL.

The President (Mr. J. H. W. Laverick): Since the last meeting the Institute has suffered another serious loss in the death of Col. T. W. H. Mitchell. I therefore ask Lt.-Col. H. Rhodes to move and Mr. E. W. Thirkell to second a resolution of sympathy.

Lt.-Col. Harry Rhodes (Rotherham): In proposing that the condolence of the Institute be forwarded to Mrs. Mitchell, Miss Mitchell, and other members of the family, I regret the necessity for so melancholy a duty. Col. Mitchell was well known to most of the members of the Institute, but I have probably known him as long as anyone here, not only professionally, but as a personal friend from boyhood, to say nothing of our association in the old Volunteer Force, and later in the Territorial Army. Other speakers at other gatherings have spoken of the loss that his death has occasioned to the whole community, and especially to the mining industry, and I do not think any words of mine are needed to emphasize our sense of this loss.

Mr. E. W. Thirkell (Aldwarke Main): It is a melancholy duty, but one the members will agree is necessary, that we should not only send an expression of condolence to the bereaved family, but enter on the minutes our appreciation of the work that Col. Mitchell did for the Institute, which was inseparably connected with his name. He was universally known as "Tom Mitchell," and was held by all in the most affectionate regard. He was one of those men who collected round themselves a circle of very sincere friends; he had a faculty for friendship, and was kind and considerate to everybody who came into association with him.

The vote of condolence was carried unanimously, all the members standing.

MEMOIR OF THE LATE COL. THOMAS WILFRED HOWE MITCHELL, V.D., J.P.

Col. T. W. H. Mitchell died at his residence, Sandygate, Wath-upon-Dearne, on Wednesday, March 9th, 1921, aged 57 years.

Col. Mitchell was born at Worsboro' Dale in 1864, and was the eldest son of the late Joseph Mitchell, of the Mitchell Main Collieries, and grandson of Joseph Mitchell, who was the first member of the family to enter the coal-trade. He received his early education at Rugby, where he obtained his football cap. He served his articles as a mining and

civil engineer under his father, obtained his colliery manager's certificate in 1886, and was elected an Associate Member of The Institution of Civil Engineers in 1888. He succeeded his father in 1895 as Managing Director of the Mitchell Main Collieries, and also as Chairman of Directors of the Mitchell Main and Darfield Main Collieries.

Col. Mitchell was a well-known figure in the South Yorkshire coal-trade, and recently succeeded the late Mr. Ralph Richardson as Chairman of the South Yorkshire Coal Owners' Association.

His connexion with The Midland Institute of Mining, Civil, and Mechanical Engineers was long and valuable. In 1890 he became the Secretary of the Institute, which position he held until he became President of the Institute in July, 1904. He served for two years as President, and since that time devoted much of his time and energy to the furthering of the objects of the Institute.

Col. Mitchell was not only a successful mining engineer and coal owner, but was a true Yorkshire sportsman, and played as hard as he worked. His interest in football and cricket never flagged, and in his younger days he was extremely fond of hunting and polo, but latterly his sports were confined chiefly to shooting and golf.

For some 35 years he was an enthusiastic volunteer, and later a Territorial officer, being gazetted in 1882 2nd Lieutenant to the 5th (V.) Battalion, York and Lancaster Regiment, which he commanded until shortly before the war. On the outbreak of hostilities in August, 1914, he at once came forward, forsaking his large business interests, and commanded for two years the Second Line Battalion of the 5th (T.) Battalion, York and Lancaster Regiment. On the battalion proceeding overseas, it was a bitter disappointment to him, and to all ranks serving under him, that on account of his age and medical category he was not allowed to go with them. But on returning to private life he devoted much of his time to the amelioration of the lot of the members of his old battalion in the line and to the support of their dependants at home. His only son was killed in a flying accident while serving in the Royal Flying Corps during the war.

The most salient feature of Col. Mitchell was his keen sense of honour, and his hatred of all that was shifty and crooked. Both in private and in commercial life his word was his bond. He was never so happy as when entertaining his vast circle of friends, or when helping some old acquaintance with whom the fates had dealt harshly. He never lost that breeziness and lack of "side" which he learnt at Rugby, and is the hall-mark of our public schools. He detested self-advertisement, and endeavoured always to avoid being in the public view; it was only his keen sense of duty that led him to consent to contest the Parliamentary division of Wentworth in the Coalition interests in 1918.

C. C. E.

ELECTRIC HAULAGE AND THE ELIMINATION OF PIT-PONIES.

By SAMUEL DIGGLE.

Introduction.—The conveyance of tubs of coal from the face to the shaft is usually performed in at least two operations—(1) the coal has to be collected from the various working-faces and taken to pass-byes or sidings, and then (2) conveyed by main haulage to the shaft. The pass-byes are kept as near the face as possible, in order to reduce the length of the secondary haulage. At the end of 1918, when it was decided to try to eliminate pit-ponies, it was difficult to obtain reasonable delivery of electrical apparatus owing to the war, and it was not until December 11th, 1920, that the last pony was withdrawn. During this period fifty-five ponies were sent out of the pit. The Haigh Moor Seam is worked at a depth of 281 yards from the surface, and the full dip is from 1 in 18 to 1 in 36 in a direction 63 degrees north-east. The section of the seam is as follows :—

	Feet.	Inches.
Top coal	1	8
Dirt	0	1
Bottom coal	1	8
Total thickness	3	5

Method of Working the Coal.—The coal is worked by the ordinary longwall advancing method (Fig. 1, Plate I.), either by bord-banks with gates 25 yards apart or with end gates 30 yards apart, breaking in at the gate-end and working bord-pieces 4 to 5 yards wide. The roof consists of sandstone, and has to be blasted down in the gates. This provides the necessary material for packing.

Output.—The average output from this seam is about 6,700 tons per week of six days. The carrying capacity of each tub is nearly 7 cwt., and approximately 20,000 tubs are handled for this output.

Arrangement of Main Roads.—The main road, which is level, runs through the centre of the royalty, and is 2,145 yards in length. It is 11 feet wide and 6 feet high, with a double track laid throughout consisting of flat-bottom rails 12 feet in length and weighing 18 pounds per yard, each joint being securely held by fish-plates and bolts. The sleepers, which measure 3 feet by 6 inches by 3 inches, are laid 3 feet apart: at intervals of approximately 20 yards a long sleeper is laid the whole width of the road, and this keeps the rails rigid and in line. The gauge is 22 inches, and the distance between the centres of the two roads is 4½ feet. The coal is hauled along this main level to the shaft by an overhead endless rope running at a speed of 1¾ miles per hour, and trains of twenty-four tubs are attached to the rope by the ordinary lashing-chain method. It should here be mentioned that part of this main road consists of a drift through a fault, dipping 1 in 6 and 150 yards long (Fig. 1, Plate I.). In this drift not more than six tubs in one train are attached to the rope; on landing at the top, four loads are coupled together, so that loads of twenty-four tubs proceed to the shaft. The rope, which is of the flattened-strand non-twisting type, is ⅞ inch in

diameter and approximately 4,400 yards long. It is driven by a 60-horsepower direct-current 500-volt motor fixed at the pit-bottom. On reference to Fig. 1 (Plate I.), it will be seen that there are nine main bords (Nos. 1 to 9) to the rise of the main level and five main bords (Nos. 1 to 5) to the dip.

Nos. 1 *and* 2 *Rise Bords and Level.*—The type of haulage here is main and tail, and the motor situated at the end of the level and marked *A* on Fig. 1 (Plate I.) works all three places; this is effected by using dead ropes in Nos. 1 and 2 bords. The motor is of 25 horsepower, the number of tubs in one train is twenty-four, and the speed is 4 miles per hour.

No. 3 *Rise Bord.*—A similar kind of haulage is adopted in this bord, the number of tubs in each train being twenty-four and the speed $4\frac{1}{2}$ miles per hour. The motor, which is of 30 horsepower, is shown almost at the bottom of the bord, and is marked *B* on Fig. 1.

No. 4 *Rise Bord.*—The type of haulage in this bord is similar to that in No. 3, and the number of tubs in each train is twenty-four. The 30-horsepower motor which drives this main-and-tail haulage is shown on the main level midway between Nos. 3 and 4 bords, and is marked *C* on Fig. 1.

Nos. 5 *and* 6 *Rise Bords.*—The main-and-tail haulage in each of these bords is worked by one haulage-gear with four drums, two of these being the main and tail for No. 5 bord and the remaining two for No. 6 bord. By this arrangement only one motor-gear and motorman is required to drive the haulage-gear for both bords. The motor marked *D* on Fig. 1 is of the same size, namely, 30 horsepower, and the number of tubs in one train in both bords is twenty-four.

No. 7 *Rise Bord.*—This is the first rise bord after leaving the bottom of the drift referred to. At the present time the coal is lowered by means of a self-acting incline; but, owing to the undulations of the ground and consequent difficulty in landing, arrangements have been made to install a 30-horsepower motor (*E*, Fig. 1, Plate I.) to drive a main-and-tail gear capable of hauling twenty-four tubs in a train at the bottom of the bord.

Nos. 8 *and* 9 *Rise Bords.*—The haulage in these two bords is accomplished by the ordinary self-acting incline, but it is intended to adopt the main-and-tail method when the roads are advanced—say, a further 100 to 150 yards.

No. 1 *Dip Bord.*—The main-rope system supplies haulage for this bord, which has been started only recently. The gear is driven by a 40-horsepower motor (*F*, Fig. 1) situated at the top of the bord.

No. 2 *Dip Bord.*—The ordinary main-rope haulage is adopted here. The tubs are hauled up the bord in trains of twenty-four, a 40-horsepower motor (*G*, Fig. 1) driving the gear.

No. 3 *Dip Bord.*—This bord is worked by the main-and-tail rope method, the 40-horsepower motor (*H*, Fig. 1) being situated at the top. At the point *K*, about two-thirds of the way down this bord, a 40-horsepower motor drives a main-and-tail gear, which is employed to collect the tubs from the various pass-byes to the junction shown at *L* on Fig. 1.

No. 4 *Dip Bord.*—The haulage in this district is effected by a 40-horsepower motor, which drives a main-rope gear situated at the top of

the bord, in the position marked *M* on Fig. 1. The trains here consist of twenty-four tubs.

No. 5 Dip Bord.—A 40-horsepower motor to drive a main-rope gear has just been installed at the top of this new bord, in the position marked *N* on Fig. 1. This motor will be capable of hauling trains of twenty-four tubs.

Near the terminus of the endless rope is a 10-horsepower electric main-and-tail gear (*O*, Fig. 1), which hauls trains of twenty-four tubs to the endless rope. There is also a similar 10-horsepower gear fixed in No. 2 Dip Bord (*P*, Fig. 1), which hauls the coal from a level to the No. 2 Dip Bord rope.

Fig. 2 (Plate I.) is a section showing the length of endless rope and the arrangement of the pulleys which carry the rope.

Advantages of Slow-speed Haulage.—The average speed of the rope in the main bords is about 4 miles an hour, and by reducing the speed to this reasonable minimum the following advantages are obtained :—

(1) The tubs are less liable to become derailed and broken, and the number of delays caused thereby is considerably reduced.

(2) There is less danger to persons travelling while the rope is in motion, as they have ample time to take refuge.

(3) The quantity of fine coal-dust deposited on the floor, roof, and sides is reduced to a minimum.

(4) Less power is required, and, therefore, smaller motors may be used.

The number of broken tubs is very small indeed. Only three tub-repairers are employed, and, in addition to repairs, these men build all new tubs, including the making of the tub-boards, which are sawn from larch logs.

Electric Power.—The electric power is generated on the premises, and, in addition to the quantity used for the haulage described, a further supply is absorbed by coal-cutting, etc., in other seams. The installation consists of dynamos coupled direct to Browett-&-Lindley high-speed compound engines. These dynamos give an output of 400 kilowatts direct current at a pressure of 500 volts.

Power Transmission.—The shaft-cables consist of two pairs of twin 19/13 armoured cable, and are secured in the shaft by strong wooden cleats 2½ feet long, on which a pair of substantial hooks are bolted and hung from each bricking-crib. These cables are taken to the distribution station situated near the pit-bottom. From this switchboard the sub-main cables are taken, as shown on the plan (Fig. 1, Plate I.), and vary in size from 19/13 to 19/17.

Disconnecting Boxes.—These boxes, which are necessary for the dividing of circuits at junctions, etc., are enclosed in flameproof cast-iron cases. They are shown on the plan as rectangular blocks on the cable-line.

Earthing.—General Regulations : Part III.—*Electricity* [Section 60] (125) (formerly Rule 8) states that :—

(*a*) "All metallic sheaths, coverings, handles, joint boxes, switchgear frames, instrument covers, switch and fuse covers and boxes, and all lampholders, unless efficiently protected by an earthed or insulating covering made of fire-resisting material, and the frames and bed-plates of generators, transformers and motors (including portable motors) shall be earthed by connection to an earthing system at the surface of the mine."

(*b*) "Where the cables are provided with a metallic covering constructed and installed in accordance with Regulation 129 (*e*), such metallic covering may be used as a means of connection to the earthing system."

All the cables are in accordance with Regulation 129 (*e*), and the boxes, motors, controllers, bed-plates, etc., are connected to the metallic covering. The actual earth-plates on the surface consist of two iron plates $4\frac{1}{2}$ feet square and 1 inch thick, and are buried about 3 feet in the ground.

Situation of Motors.—Very careful consideration should be given to the selection of sites for the fixing of motors, especially with reference to safety and permanency. On the haulage plan (Fig. 1, Plate I.) the direction of the air-currents is shown, and it will be noticed that all the motors are placed in the intake airway, and will remain so during the life of the seam.

Section 60 (1) of the Coal Mines Act, 1911, states that:—

"Electricity shall not be used in any part of a mine where, on account of the risk of explosion of gas or coal-dust, the use of electricity would be dangerous to life," etc.

The same Section (paragraph 2) states also that:—

"If at any time in any place in the mine the percentage of inflammable gas in the general body of the air in that place is found to exceed one and a quarter, the electric current shall at once be cut off from all cables and other electrical apparatus in that place, and shall not be switched on again as long as the percentage of inflammable gas exceeds that amount."

In view of the foregoing, and the fact that the whole of the coal is hauled from the in-bye pass-byes to the shaft by electricity, it may be interesting to note that, as has already been stated, all the electric apparatus is fixed permanently in the intake airways.

It should be mentioned that this installation has been so arranged that no further hands will be required at any time on this important class of labour despite the future extension of the workings.

The examination of electric and mechanical machinery and all cable-lines, junction-boxes, switches, etc., is made by competent persons, and their reports are entered in a daily log-book provided for the purpose.

As regards the reliability of electrical apparatus, I need only say that during the year 1920 we were entirely free from any electric breakdown, and it is my opinion that the immunity from any stoppage was due to the following:—

(1) Allowance for ample margin in the power of the motors;
(2) Regular examination by competent persons;
(3) Installing the very best quality of apparatus; and
(4) Thorough instruction to all motor-drivers.

It is also essential that the very best controllers should be used, and in most cases continuously rated, otherwise trouble may ensue, causing heating, and sometimes burning-out, of the controller resistances.

With regard to the mechancal part of the haulage-gears, only one small stoppage occurred, and this was caused by the breaking of a spur-wheel on one of the 10-horsepower gears.

The aggregate length of all ropes working daily in this seam is 25,150 yards, the sizes varying from $\frac{7}{8}$ to $\frac{3}{8}$ inch in diameter.

The reason for adopting the non-twisting flattened-strand type of endless rope was in order to remove the difficulty caused by other ropes twisting, which resulted in the chain becoming entwined round the rope,

with consequent delays in lifting the front end of the empty tub off the rails. The flattened-strand rope does not twist, and what was once a serious hindrance was eliminated by the use of this type of rope.

These ropes are also stronger and more solid than the other ropes, and therefore the heavy strain caused by the frequent dead loads being attached to the moving rope does not have the same injurious effect.

Signals.—Electric signals are installed throughout the pit.

Telephonic Communication.—The telephone exchange-board is fixed in a separate compartment in the box-hole, and telephones are provided at a number of the main junctions. It was recently decided to have a telephone at all the in-bye pass-byes and also at the junction of each bord leading from the endless-rope level. It is possible that the output in a particular district or districts might be retarded by the inadequate supply of empty tubs, whilst at the same time other districts are supplied with more than are required. When the installation of these telephones is complete, we shall be able to distribute evenly the supply by one man, who will remain in the box-hole; and by giving his whole attention to the telephones and by constant communication with the youths employed in the pass-byes and junctions, he will be able to direct the proper distribution of the tubs.

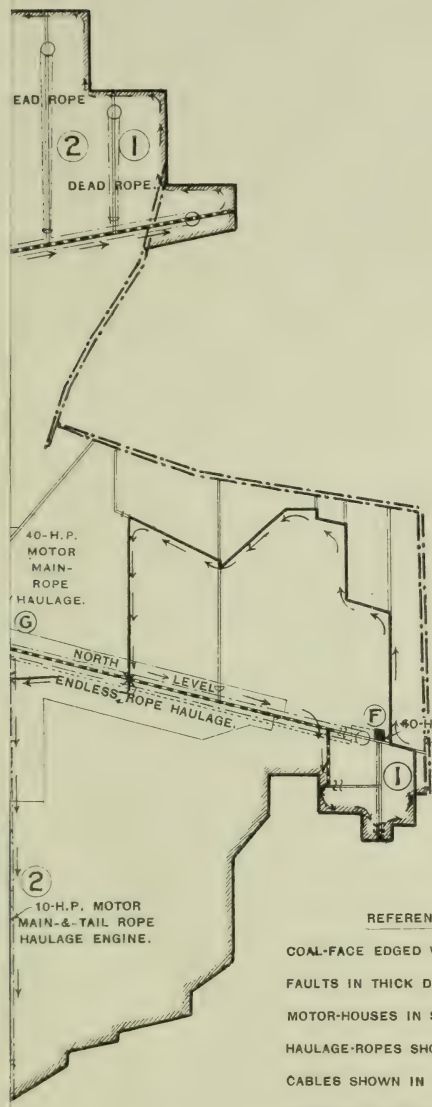
Every method which tends to prevent waste of labour, and to prevent idle hours and half-hours from this or from any other cause calls for the greatest care that a manager can exercise. Where there are workers who are in receipt of an allowance in order to make up their wage, and are compelled to spend some of their time in idleness, this tends to discourage any desire they may have to try to *earn* their wages.

It will be seen on reference to the plan (Fig. 1, Plate I.) that there are twelve junctions at right-angles to the main level, and that the endless rope is carried clear of the tubs by the ordinary "mushroom" pulley fixed in pairs on to a short vertical shaft. The clearance between the top of the tub and the pulley is about 4 inches. By this arrangement the endless rope is always sufficiently high to allow of the passage of full and of empty trains from each junction, which are then attached to the endless rope by the lashing-chain.

As to comparative costs, it is difficult to arrive at the exact saving which was effected, but it was very considerable, and the results obtained by the electric haulage described in this paper have fully justified its introduction and the elimination of the pit-ponies.

I make no claim to there being anything new in this paper, but I hope that the clear description of the general arrangements that have been carried out in actual practice may be useful to others. The conveyance of coal from the face to the shaft is a very interesting subject to all mining engineers, and the Chairman and Managing Director (Sir Joseph Hewitt, Bart.) has always expressed his desire to withdraw pit-ponies wherever possible. I have received great help and encouragement from Sir Joseph in carrying out the alterations herein described.

The PRESIDENT (Mr. J. H. W. Laverick): I am sure that all the members will congratulate Mr. Diggle on having succeeded in eliminating his last pit-pony. In the old days the old-fashioned fitting-shops were equipped with a line of shafting and pulleys and with belting driven by a steam-engine, which worked the various machines in the shop. You will not find in a modern fitting shop to-day that shafting or steam-engine,



REFERENCE TO FIG. 1.

COAL-FACE EDGED WITH FINE LINES	
FAULTS IN THICK DOT & PECK LINES.	
MOTOR-HOUSES IN SOLID BLACK	
HAULAGE-ROPES SHOWN IN THIN DOT & PECK LINES.	
CABLES SHOWN IN FINE DOTTED LINES.	
DISCONNECTING BOXES ON CABLE-LINE IN WHITE.	
INTAKE AIRWAYS SHOWN IN THICK DOTTED LINES.	
RETURN AIRWAYS SHOWN IN THICK LINES.	
GENERAL DIRECTION OF AIR-CURRENT INDICATED BY ARROWS.	→
DOORS, SHEETS, STOPPINGS, AND AIR-CROSSINGS SHOWN BY USUAL SYMBOLS.	

Chains to 1 Inch.

PULLEYS WHICH CARRY THE ROPE.

RETURN WHEEL.

FIG. 1.—HAULAGE PLAN, DECEMBER, 1920.

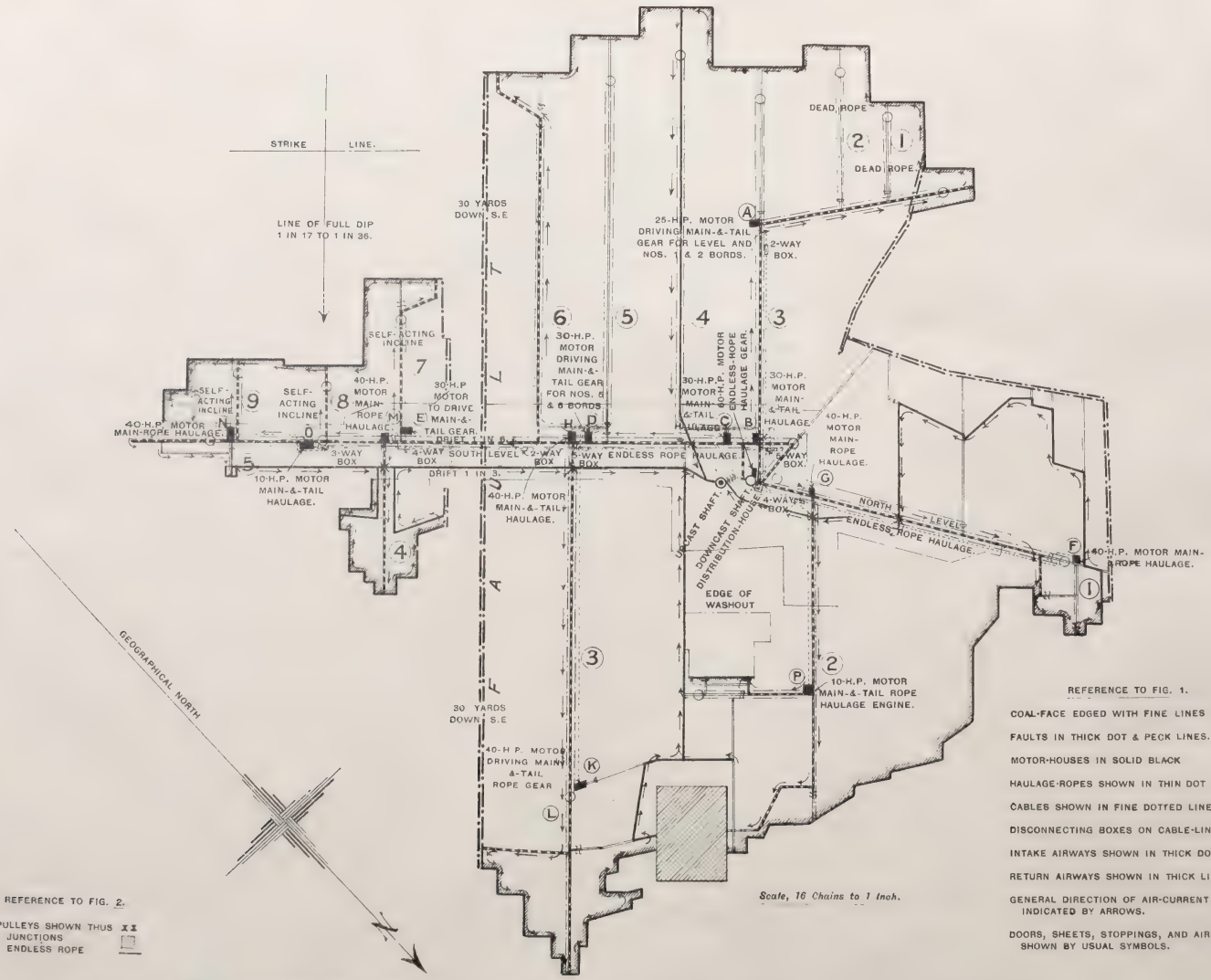
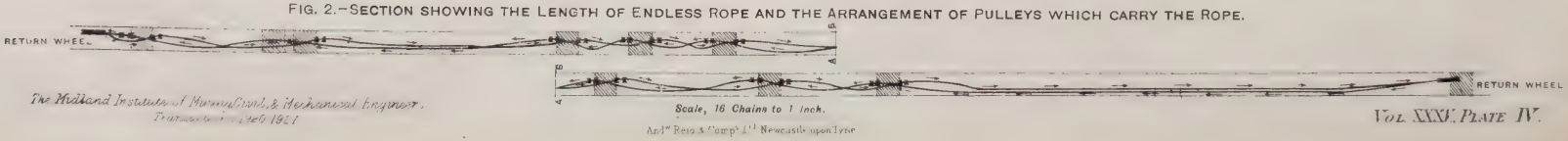


FIG. 2.—SECTION SHOWING THE LENGTH OF ENDLESS ROPE AND THE ARRANGEMENT OF PULLEYS WHICH CARRY THE ROPE.



but instead a little motor attached to each of the machine-tools. Mr. Diggle has applied that principle to his underground haulage: instead of taking a strap-rope down the pit from the surface, he has taken a fixed cable, which does not wear out at anything like the same rate as a moving cable. That is one great achievement in the direction of economy—to do away with the moving strap-rope with its wear and tear, and to replace it by a stationary cable. Through that cable electric current is conveyed underground, not to one motor, but to a number of motors, which actuate the respective haulages. That, I think, is a distinct advance on old-fashioned practice; but whether the cost of the electric current is less or more than the cost of feeding the ponies, Mr. Diggle does not say. Perhaps before the discussion is ended he will enlighten us in regard to that point. Just as pony feed to-day is very dear, so also is electric current proportionately dearer.

Mr. E. W. Thirkell (Aldwarke Main): On examining the plan and on hearing Mr. Diggle's description of the system, it seems at first sight an ideal arrangement and one to be followed when laying out a new pit; but when it comes to the practical application, I rather doubt whether it is possible to eliminate pit-ponies entirely. Mr. Diggle's is the only case of which I know where there are no pit-ponies at all. With regard to haulage, some calculations were made some years ago in connexion with the colliery with which I was associated, and it was found that it would pay to put in a small electric haulage, or a haulage worked by compressed air, where two or three ponies could be taken out. The cost was, of course, an important item, and I hope Mr. Diggle will say more on that point. Certainly the haulage system described by Mr. Diggle is an ideal one if the cost works out favourably.

Lt.-Col. Harry Rhodes (Rotherham): When ponies are once in a pit, it is very hard to displace them, because, apart from all humanitarian considerations, it is undeniable that if you have conditions where a pony can take in, say, six empty and bring out six full tubs of an average capacity, there is very little room for economy. In these days of shortened hours of labour, however, it has to be remembered that a pony when idle has to be fed and cared for, whilst an electric motor or compressed-air engine ceases to be a charge when standing idle, except for depreciation, etc. With regard to economies in the use of secondary haulage, I found in pre-war days that if one could spend £70 and put down a small compressed-air engine or electric motor and save one pony, it was a paying investment. At the present time we would have to multiply that figure by three, but even then it would pay. I had an opportunity of seeing Mr. Diggle's plant when the electric installation was only partly completed, and at that time talked over with him his reasons for adopting continuous current. The reasons he gave were quite satisfying so far as I was concerned, but perhaps for the benefit of others Mr. Diggle will repeat them. It seems to me that with the comparatively low voltage he will find certain difficulties in the use of direct current if the present installation is extended.

Mr. Diggle's method of earthing is by attaching the cable to a buried plate. I think Mr. Diggle will find in course of time that the connexions with the plate, unless very carefully watched, may break away, and he may find himself without an earth. I have found that a very good earth is obtained by attaching the earthing-cable to the end of a 9-foot cast-iron pipe set up in the ground and filled with coke; if placed near a water-tap, it will be found that the coke is always saturated, thereby

ensuing a very good earth and providing easy means for examining the attachment. With regard to signalling, I found at a colliery of which I recently took charge the old rapper system in use, and I criticized it from the endless-rope point of view; but I have come to the conclusion that for secondary haulage and for distances up to 300 yards, or even longer, electric signals are an unnecessary complication, and that the old system is cheaper and more reliable.

Mr. Robert Clive (Bentley): I assume that there is hand haulage up to the pass-byes. There appears to be some distance between the point where the haulage commences and the face, but, as Mr. Diggle has pointed out, the tubs are of only 7-cwt. capacity, and I conclude, therefore, that there is hand-tramming to that point. In the collieries round Doncaster, where the tubs have a capacity of something like 15 cwts., it would not be possible to have hand-tramming for any considerable distance; in fact, 30 to 45 feet is the usual distance. It has often been suggested to me that it is a good policy to get ponies out of the pits, and there are, in fact, two or three pits where the ponies have been taken out. A few years ago I went very carefully into the comparative cost of districts where the secondary haulage was by horses and of districts where this was mechanical, and in certain instances I can agree with Mr. Diggle that secondary haulage is both economical and the correct procedure; but I question whether in flat seams it is an economy. In the costs I took out, after going into the matter very carefully and taking into consideration both the cost of feeding the ponies, the value of the ponies, their length of life, etc., and in the case of compressed-air haulage the cost of the haulage itself, cost of repairing haulage-houses, and the maintenance of the signalling, I found in some cases that the figures were considerably in favour of horse haulage. That is why we have not taken out all the horses at Bentley Colliery. The actual cost in this case came to 1s. 8d. for mechanical as against 11½d. for horse haulage. But in the particular district where there is mechanical haulage, horse haulage could not be done for 11½d., as the horses can pull only one or two tubs at a time. In my opinion, where a horse can pull only one tub at a time there is certainly a great deal to be said in favour of mechanical haulage, and possibly also where it can pull only two tubs; but where a horse can pull three 15-cwt. tubs and take in three empties, I think that horse haulage is the better.

There is another point which should not be overlooked in considering the benefits of mechanical haulage. Where a lot of ripping is required there is great risk of the signalling apparatus being broken, thus causing much delay. In the Barnsley Seam it is necessary to rip from 10 to 15 feet in several rippings; a great deal of supervision has to be exercised, and considerable cost is incurred in maintaining the signalling efficiently. In the case of mechanical haulage when a large number of tubs are being brought out at a time a stoppage is much more serious than when only one horse is involved. I should like to know why the main-and-tail-rope system was specially introduced. I am not quite clear whether there is a double track for the whole length, or a single track with a pass bye at each end, on the secondary haulage-roads.

Mr. John Gill (Normanton): The first point that strikes me is the number of motors employed, and the large number of junctions on the main road also seems to me to be an objection to Mr. Diggle's lay-out of the scheme, because if there is a stoppage anywhere the whole haulage will come to a standstill. There are so many places where the tubs might

be stopped that it would appear that a number of men will be required to keep the installation running efficiently. What is the average distance from the face to the return?

Mr. William Hay (Chapeltown): The only objection I can see to Mr. Diggle's system is that it does not bring the tubs right from the working-face. I believe that some system of haulage should be devised by which the tubs can be brought right up to the face, and economy thereby effected by avoiding the need for adult labour to push the tubs. At one of my company's collieries every tub is brought up to the working-face in the thin seams. Mr. Diggle's plan seems somewhat complicated, but he has already told us that he has run this system of haulage for a considerable time without stoppage, and that fact seems to answer some of the objections that have been raised.

Mr. M. W. Waterhouse (Wakefield): I consider Mr. Diggle has shown a great amount of foresight and courage in putting his plan into operation. I am particularly impressed by the way in which he has provided for the future, and hope he will not be disappointed in his expectation that he will be able to manage without increasing the number of men. Like Mr. Hay, I am rather disappointed to find that although the ponies have been eliminated, hand-trammers have been retained. I spent eighteen years in the same seam, and hand-tramming was unknown during the whole of that period; in fact, I believe that the colliery has worked for over sixty years without hand-tramming. I strongly urge Mr. Diggle to persevere along the lines he has already taken, and not be content until he has eliminated not only the pony but the hand-trammer. At a colliery with which I was connected twenty years ago the main haulage worked quite close to the face, but there was a considerable distance of hand-tramming along the face itself; it was a somewhat difficult problem to eliminate the hand-tramming, as a peculiar system of working had been adopted. A pair of main roads 100 yards apart went the full length of the royalty, and there struck a face 430 yards long; then hand-tramming was done along the whole of the face to the main roads. I had to adopt rather a peculiar system to eliminate the hand-tramming, which served its purpose very well indeed. I put down a small portable endless-rope plant, the whole affair no bigger than a 9-cwt. tub, and arranged to haul by endless rope along the greater portion of that face—about 380 yards. It served its purpose to finish the whole of that panel of coal. When the colliery was reopened with about 200 yards of extra cover, I decided, in view of my experience in that district that there was no need for these enormously long faces, and I therefore substituted roads 100 yards apart, installed motors at the top of the solid road gates, and hauled direct from the face. In that case there were 12-horsepower motors, pulling direct from the coal-face, the coal in turn being hauled by endless ropes driven by a 150-horsepower motor, which landed the coal to the main haulage, the engines (two sets of pairs of 25 inches) being on the surface. It was a dip-working in a thick seam. In this case there were no ponies in the pit, and hand-haulage was restricted entirely to the face itself; the stalls were each 50 yards long; a little haulage-rope ran round a set of points into the coal-face and pulled out eight tubs at a time. I have known one of these direct-rope plants be responsible for as much as 380 tons in one shift. I am very anxious to see this country's superiority maintained, and dislike seeing the Americans entering the European market; in America they do not waste labour in hand-tramming, in the same way that in this country we refrain from carrying the coal out in baskets.

Mr. T. L. SOAR (Barnborough): At my colliery the installation is one of compressed air, as I have very little faith in the use of electricity for secondary haulage in the deep mines working the Barnsley Seam. I notice that on Mr. Diggle's plan all the gates are straight and no crossgates are shown. How were the crossgates worked after the first or second was put in, so that the motor could be in the intake air? How was the cable in this case dealt with? Was it hung from the roof, fastened on props, or buried, and was the roof good? It is doubtless good policy to do away with the ponies, and in view of my experience if it were necessary to withdraw the ponies, I doubt whether we would send them down again. Our colliery would then be worked without ponies and by the compressed-air system. Mr. Diggle's plan shows small motors with drums; will he be able to go a farther 300 or 400 yards with the motors in the same position?

Mr. JOHN MINNIKIN (Hickleton): We use compressed-air haulages, and some ponies where the seam is very flat; but instead of having the main-and-tail-rope system, there are two single ropes. Owing to the seam being flat, it often happens that a pony is put on the front of the train to pull in the empties and rope, and then the engine pulls the loaded tubs back. I should like to know whether Mr. Diggle has obtained entire satisfaction with his telephone installation; it appears to be an ideal method, but with so many junctions down the main road it might happen that Nos. 1 and 2 junctions might get all the tubs required, but at the junctions farther along only what tubs were left.

Mr. C. F. DYER (London): Can Mr. Diggle give any more information about the electrical lay-out and the motors and switch-gear used? Are they totally-enclosed motors, and are the switches of the oil or of the ordinary ironclad type? It would be interesting to electricians to have more information on these points, and also with regard to the application of the Rules and Regulations issued in 1920, which require that efficient means shall be provided in respect of each separate circuit for cutting off all pressure automatically from that circuit or part of the circuit affected as may be necessary to prevent danger. That, I believe, will in many cases affect the lay-out of an electric system.

Mr. SAMUEL DIGGLE (Carlton, Barnsley): With regard to the question raised by Lt.-Col. Rhodes as to why continuous current was used as against alternating current, it was probably because I was better acquainted with direct current and had not the same experience with the other kind. As regards their respective reliability, I can only repeat that I did not experience a single breakdown during 1920. As to the comparative efficiency of alternating current, I am not qualified to speak. With regard to the gradual reduction of pressure as the cables extend, I must again point out that no further extension of cable will be necessary. I have had no trouble with the cables attached to earth-plates on the surface; they are attached by cross-bolts in the vertical plates.

In reply to Mr. Clive, hand-trammers are employed at the face. In Mr. Clive's case larger tubs are used, as the seam at Bentley is very much thicker than I have ever been fortunate enough to work. It must be admitted that it is much more difficult to eliminate ponies either in favour of compressed air or of electric haulage if one has to go to the face in every gate in the seam, especially in thin seams. It would be more encouraging to make the experiment in a thicker seam where a larger quantity of coal is produced in one gate. It is obvious that for a given output the number of men employed on this class of labour in a thin

seam would be very much greater per ton than in a thicker seam. As regards the signalling apparatus being destroyed and consequent trouble arising through blasting, in the seam referred to we have a rock roof and a badly lifting floor, and it is only by constant back-ripping and blasting that we are able to keep going; but no difficulty has been experienced in maintaining the signals in an efficient state. The reason why the main-and-tail type of haulage was introduced was twofold—first because it would be impracticable in the seam in question to maintain a double line of rails in all the main roads, owing to the lifting floor and the squeezing in of the roadways. A good single road could be maintained, but the cost of making a double line would be prohibitive and unnecessary. The second reason was obvious: as the gradient was undulating, it became necessary to apply the tail-rope, and this was found to be a blessing in disguise. At one time there was a wheel at the top of each main road, and the full train gravitated to the bottom, and in order to get over the undulations a tremendous speed was necessary, which resulted in the smashing of tubs and caused delays. With the tail-rope one always has control of the load and is able to adjust the speed, up to 4 miles per hour, as desired, with the result that delays are very rare and the breaking of tubs is almost eliminated.

Mr. Gill thinks that the number of motors is high. We obtain an output of nearly 7,000 tons per week from this 40-inch seam, and I consider the number of motors is small for this large quantity. The number of junctions also appears to Mr. Gill to be a very serious matter from the point of view of delays and stoppages. I am pleased Mr. Gill has raised that point, because it is one of our worst difficulties and has caused great trouble. When passing these junctions and crossing the pulleys, the rope sometimes lifted the empty tubs on to the mushroom pulleys, broke the chains, and smashed the tubs. That defect was eliminated by the use of the flattened strand rope, which is free from a twisting tendency, and this has proved very satisfactory, although there were some stoppages. The average tramming distance is about 140 yards. This is admittedly a difficulty; all pits have some kind of haulage, and most pits have a mixture between mechanical and pony haulage; it is only by a really earnest attempt to extend mechanical haulage that ponies can be eliminated at all.

I can assure Mr. Waterhouse that I am absolutely convinced that no further increase of haulage hands will be necessary.

Mr. Soar is satisfied with compressed air, but he will, I think, admit that the most efficient transmission of power is by electricity. There are, however, doubtless excellent reasons why he uses compressed air. The crossgates are put in at the face. The roof is of rock. As a rule ordinary drill-holes about 2 inches in diameter are drilled, and in them are inserted round wedge-plugs, on which the cable is hung. Most of these have never been disturbed since first put up. With regard to the size of the drums, in view of the extension of the rope this was of course foreseen and provided for. With regard to Mr. Soar's statement that no saving was found as between mechanical haulage and ponies, so far as my colliery is concerned, although I cannot go into details, I can say that a very substantial saving has been effected.

Mr. Minnikin asked whether I was satisfied with the telephone system. I can assure him that it is one of the most satisfactory features of the whole scheme, and better than the old system for the proper distribution of the tubs, which is, of course, a very important consideration in such a scheme.

In reply to Mr. Dyer, the motors were not all of the totally-enclosed type—that is one of the advantages in keeping them in the intake; in other seams where there are coal-cutters all the motors are totally enclosed; those in use on the haulage plant are protected, but not totally enclosed, and that also is a saving. The switchgears and disconnecting-boxes are all flametight, with proper armoured-cable gland joints, in accordance with the Regulations. I do not quite understand what Mr. Dyer means by more information about the lay-out of the cables. I might have mentioned in the paper that there are the ordinary automatic cut-outs at various junctions. If a leakage occurs in any one district, the short-circuiting acts on this automatic cut-out which cuts off the current.

The further discussion of the paper was adjourned.

Mean Magnetic Declination (West) for each Two hour Interval from April 3rd to April 30th, 1921, as recorded at Kew Observatory, Richmond.

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
	April.														
Sun. ..	3	1	22·0	22·0	22·0	20·0	19·5	24·5	30·5	29·5	25·5	23·5	22·0	19·5	23·5
Mon. ..	4	0	22·5	22·0	21·5	19·5	19·0	23·5	27·5	26·5	23·5	22·5	22·5	22·5	23·0
Tues. ..	5	0	22·0	22·0	21·5	20·0	19·0	23·0	28·0	26·5	23·5	22·5	22·0	21·5	22·5
Wed. ..	6	0	19·5	19·0	19·5	19·0	19·5	23·0	27·5	26·5	23·0	22·0	22·0	22·0	22·0
Thur. ..	7	0	22·0	22·0	22·0	19·5	18·0	22·0	26·5	26·5	24·0	23·0	22·0	22·0	22·5
Fri. ..	8	0	22·5	22·0	20·0	18·5	18·5	24·0	30 0	30·0	25·0	21·5	20·5	20·5	23·0
Sat. ..	9	1	22·0	21·5	20·5	18·0	18 0	23·0	29 0	30·0	27·5	28·5	24·0	21·5	23·5
Sun. ..	10	1	17·5	17·5	18·5	19·5	21·0	25·5	30·0	28·5	25·0	19·5	19·0	17·0	21·5
Mon. ..	11	1	17·5	16·0	18·5	19·0	19·5	23·5	27·5	27·5	25·5	24·0	23·0	22·0	22·0
Tues. ..	12	0	22·0	20·0	19·5	19·0	20·0	25·0	31·0	30·5	25·5	23·5	23·0	22·0	23·5
Wed. ..	13	1	22·0	24·0	27·5	23·5	22·5	25·0	27·5	26·5	23·0	20·0	18·5	19·0	23·0
Thur. ..	14	1	16·5	18·0	19·5	19·0	20·0	25·0	29·5	28·0	24·0	19·0	18·5	17·0	21·0
Fri. ..	15	1	16·5	17·0	18·5	17·5	18·5	24·0	29·0	29·0	25·0	20·5	20·0	19·0	21·0
Sat. ..	16	1	19·5	18·0	17·5	17·5	20·5	27·0	32·0	30·0	26·0	22·0	18·5	19·0	22·5
Sun. ..	17	1	21·0	18·0	18·0	17·0	18·5	23·5	27·5	26·0	23·0	21·0	20·5	21·0	21·5
Mon. ..	18	1	22·0	21·5	20·5	18·0	18·5	24·0	27·5	28·5	25·5	21·0	21·5	23·0	22·5
Tues. ..	19	1	22·0	15·5	16·0	15·5	18·5	24·0	28·0	24·5	21·0	21·0	21·5	21·5	21·0
Wed. ..	20	1	22·0	22·0	23·0	21·5	20·0	23·5	27·5	27·0	22·5	16·5	19·0	21·5	22·0
Thur. ..	21	2	20·0*	26·5*	31·5*	26·0*	22·0	27·0	30·0	26·0	22·0	20·0	22·0	21·5	24·5
Fri. ..	22	1	25·0	22·5	19·0	17·5	18·0	24·0	29·5	27·5	24·0	23·0	16·5	13·5	21·5
Sat. ..	23	1	22·5	20·5	19·0	16·5	17·0	24·5	31·0	27·0	23·5	21·5	20·0	21·0	22·5
Sun. ..	24	0	23·0	24·5	22·0	18·5	18·5	24·0	28·5	27·5	24·0	21·5	21·5	20·5	23·0
Mon. ..	25	0	22·5	23·0	20·5	17·5	18·0	23·5	27·5	26·5	23·5	21·5	21·0	20·0	22·0
Tues. ..	26	0	20·5	20·5	19·5	18·5	18·0	22·0	26·5	26·5	23·5	21·5	20·5	21·0	21·5
Wed. ..	27	0	21·0	21·0	19·5	17 0	17·5	22·5	26·5	26·0	23·5	22·0	22·0	21·0	21·5
Thur. ..	28	0	21·0	20·5	19·5	18·5	19·0	23·0	26·5	25·0	23.5	23·0	22·5	21·5	22·0
Fri. ..	29	2	20·5	19·0	19·5	19·0	22·0	28·0	32·0	33·0*	23·0*	23·5	22·5	21·0	23·5
Sat. ..	30	0	20·0	19·5	18·5	17·0	19·5	24·0	26·5	25·0	23·0	22·0	22·0	21·5	21·5

Diurnal Inequality (*i.e., departure from mean value for day*).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
May, 1920	−0·9	−1·4	−1·7	−2·3	−3·2	−4·3	−4·4	−3·8	−2·3	+0·3	+2·8	+4·8
April, 1921 ..	0·9	−1·2	−2·0	−1·8	−2·0	−2·5	−3·9	−4·4	−3·4	−1·4	+1·7	+4·8
April, 1920	−1·7	−2·0	−1·5	−1·3	−1·6	−2·4	−3·7	−4·5	−3·8	−1·8	+1·5	+4·6

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
May, 1920	+5·7	+5·4	+4·1	+2·7	+1·5	+0·3	−0·2	0·4	−0·4	−0·4	−0·9	−1·1
April, 1921	+6·7	+6·6	+5·3	+3·5	+1·9	+0·3	−0·3	−0·5	−1·2	−1·8	−2·0	−1·3
April, 1920	+6·9	+6·8	+5·3	+3·2	+1·8	+0·3	−0·2	−0·5	−1·0	−1·4	−1·4	−1·6

* Large disturbances during this interval.

Mean Value for Month.

May, 1920.	April, 1921.	April, 1920.
14° 31·9	14° 22·3.	14° 32·7.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE,
APRIL 2ND, 1921.

LT.-COL. F. R. SIMPSON, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated:—

HONORARY MEMBERS—

Mr. ROBERT GEORGE CARRUTHERS, Geological Survey, 4, Mosley Street, Newcastle-upon-Tyne.

SIR AUBREY STRAHAN, K.B.E., Fairfield, Goring, Reading.

MEMBERS—

Mr. JOHN TRAVERS LAWRENCE BAINBRIDGE, Engineer, Commercial Union Buildings, Pilgrim Street, Newcastle-upon-Tyne.

Col. NICHOLAS TIMOTHY BELAIEW, C.B., Metallurgist, 57, Cornwall Gardens, South Kensington, London, S.W. 7.

Mr. THOMAS BURT, Colliery Under-manager, Hill House, Washington, Washington Station, County Durham.

Mr. EDWARD TAYLOR CHEESMAN, Junr., Colliery Under-manager, Clara Vale Colliery, Ryton, County Durham.

Mr. JHAVERILAL KALYANRAY DHOLAKIA, Colliery Manager, Joyrampur Collieries, Jharia P.O., Manbhum, Bihar and Orissa, India.

Mr. WILLIAM JONES, Colliery Manager, East Hetton Colliery, Coxhoe, County Durham.

Mr. ERNEST MINTO, Colliery Manager, Chesterholme, North Biddick, Washington Station, County Durham.

Mr. OSWALD MINTO, Colliery Under-manager, 1, North Terrace, New Lambton, Fence Houses, County Durham.

Mr. UPENDRA NATH MUKERJI, Sub-Divisional Officer, P.W.D., Asansol, E.I.R., Burdwan, Bengal, India.

Mr. JACOB SALESTEN PERERA, Engineer, 144, St. Vincent Street, Glasgow.

Mr. JOHN RIVERS, Colliery Manager, The Villas, Thornley, County Durham.

Mr. HUBERT FRANCIS GARDNER ROOSE, Mining Engineer, 37, Castleton Mansions, Riverview Gardens, Barnes, London, S.W., 13.

Mr. WILFRED WALTER VARVILL, Mine Manager, c/o Greenhaugh Mining Company, Limited, Greenhow Hill, Pateley Bridge, Harrogate.

Mr. ARTHUR WELSH, Colliery Manager, Garden House, Shildon, New Shildon, County Durham.

ASSOCIATE MEMBERS—

Mr. CORNELIUS BUSSER, Haringvliet 82, Rotterdam, Holland.

Mr. ERIC JOHN PROCTOR, Abington, Moorside, Fenham, Newcastle-upon-Tyne.

ASSOCIATES—

Mr. PETER BURDESS, Stoneman, 61, Frederick Street (S), Meadowfield, Durham.

Mr. JOSEPH HODGSON, Assistant Master Shifter, 8, West Terrace, Waterhouses, Durham.

Mr. THOMAS HUDSON, Deputy Overman, Rose Street, Trimdon Grange, County Durham.

Mr. MATTHEW JOHNSON LAVERICK, Master Wasteman, 15, Front Street, Trimdon Grange, County Durham.

Mr. THOMAS LINSLEY, Coal Miner, 25, Elliott Street, Sacriston, Durham.

Mr. STEPHEN BRADLEY MARR, Stoneman, 13, Durham Road, Bowburn, Coxhoe, County Durham.

Mr. JOSEPH STOBBS, Chargeman, 12, Langley Street, Langley Park, Durham.

Mr. MATTHEW HENRY WATCHMAN, Deputy Overman, 4, Rogerson's Terrace, Croxdale Colliery, Durham.

STUDENTS—

Mr. NORMAN KENDALL GREY, Mining Student, Manor House, Broomhill, Acklington, Northumberland.

Mr. ROBERT DAWSON HUNTER, Mining Student, 12, Ushaw Terrace, Ushaw Moor, Durham.

Mr. EDWARD LESLIE NICHOLSON, Mining Student, 35, Kenilworth Road, Newcastle-upon-Tyne.

Mr. ROBERT WILLIAM ROWELL, Coal Miner, 31, John Street, Kimblesworth, Durham.

Mr. ROBERT CLAYTON TULIP, Coal Miner, 10, Booth Street, Felling, Gateshead, B.O.

Mr. ALBERT EDWARD WARD, Coal Miner, 9, North Terrace, Esh Winning, Durham.

Mr. NORMAN ANTHONY WELSH, Linesman, 16, Railway Terrace, Usworth Colliery, Washington Station, County Durham.

Mr. E. W. Milburn read a paper on "A Self-acting Jig, with Intermediate Landings."*

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* *Trans. Inst. N. E.*, 1920-1921, vol. lxxi., page 57.

THE MINING INSTITUTE OF SCOTLAND.

FORTY-FOURTH ANNUAL GENERAL MEETING,

HELD AT THE ROYAL TECHNICAL COLLEGE, GLASGOW, APRIL 9TH, 1921.

MR. ROBERT McLAREN, M.P., PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were declared elected :—

MEMBERS—

Mr. MALCOLM KENNETH CLARKE, Mining Engineer, Burma Corporation, Bawdwin P.O., Northern Shaw States, Upper Burma.

Mr. ROBERT CRAWFORD, Colliery Agent, Glencraig House, Glencraig, Fife.

Mr. WILLIAM LOUDON, H.M. Inspector of Mines, 100, Dewar Street, Dunfermline.

Lt.-Col. ALAN STEIN, M.C., Firebrick Manufacturer, Quarter House, Denny, Stirlingshire.

Mr. JOHN WILSON, Mining Lecturer, Redlands, 52, Kirkness Street, Airdrie.

Mr. JAMES HAMILTON, Colliery Manager, Hillhouse. Plean, Bannockburn, Stirlingshire.

Mr. DUDLEY SHAW NEWEY, Assistant General Manager, Plean Colliery, Plean, Bannockburn, Stirlingshire.

ASSOCIATE MEMBERS—

Mr. JAMES BARR, Oversman, Station Road, Kelty, Fife.

Mr. DANIEL GIBSON, Mining Engineer, c/o Bank of New Zealand, 1, Queen Victoria Street, London, E.C. 4.

Mr. ROBERT HUNTER, Spare Colliery Official, Woodbank Fens, by Windygates, Fife.

Mr. JAMES WARDLAW, Steel Manufacturer, Violet Bank, Bathgate.

ASSOCIATES—

Mr. ROBERT DESMOND FORRESTER, Mining Student, Annfield, Stirling.

Mr. HERBERT NISBET, Mining Student, 33, Hillside Crescent, Edinburgh.

Mr ALEXANDER SCOBBIE, Mining Student, Burnbank, Thornton, Fife.

Mr. JOHN H. STEWART, Mining Student, Fushiebridge, Gorebridge, Midlothian.

Mr. LEOPOLD ALFRED WOODS, 82, Pitt Street, Edinburgh.

STUDENTS—

Mr. DAVID McMILLAN McNAIR, Mining Student, Cramond Brig Hotel, Cramond Bridge, Midlothian.

Mr. JOHN MARTIN CALDWELL, Mining Student, Woodside, Linlithgow.

ABSTRACT OF FORTY-THIRD ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

The number of members on the roll is 683, being a net increase of 21 compared with the previous year.

A notable and encouraging feature has been the large proportion of young men who have joined as Associates and Students, as compared

with the number admitted as Members and Associate Members. While the younger men are welcomed to the lower grades of membership, the members ought to use their influence to induce those having the higher qualifications to become Members of the Institute.

In addition to the 683 members on the roll, twenty-two are subscribing firms who pay an annual subscription; but the Council think that this number might be considerably increased.

An excursion down the Firth of Clyde was held in September, 1920, in which a large number of the members and their ladies took part. The annual dinner was held in Edinburgh on Saturday, February 5th, 1921, at which over 130 members and ladies were present.

The Council has to record with regret the deaths of five members during the past year, namely, Mr. William Adam, Mr. Hugh Crichton, Mr. James Gardner, Mr. Archibald McNeil, and Mr. David Rankine. Mr. Rankine had been a member of the Institute since 1879, and was well known as a mining engineer throughout the Scottish Coalfields.

The Council regrets that the necessity has again arisen to increase the subscriptions of the members. This has been due to the greatly increased costs for printing, stationery, postages, the increase in the Call per member to The Institution of Mining Engineers, etc.; and it was found that if the Institute was to be carried on efficiently and its status maintained, a considerable increase in income was necessary.

The accompanying balance-sheet shows that the financial position of the Institute, notwithstanding the heavy drain on its resources, is fairly satisfactory. This, however, is due largely to the subscriptions received from the subscribing firms, and the payment of £70 for two life-memberships.

The PRESIDENT (Mr. Robert McLaren): I need scarcely say that the Council regrets as much as any one that the subscription rates have had to be increased. I may explain, however, that this Institute does not stand alone in this respect, as the other Federated Institutes have had to do likewise. When matters become normal again, the Council will doubtless consider whether the old rates of subscriptions may not be reverted to once more.

Mr. G. L. KERR (Secretary and Treasurer): It will be seen from the balance-sheet that the total income is £1,635 8s. 4d., and if from that amount the balance of £317 at the bank is deducted, there remains the sum of £1,318, which represents our actual expenditure. If that amount be divided by 683—the number of members of all classes on the roll—it will be found that the administration expenses of the Institute work out at 38s. per member. That is the principal reason why the subscription rates have had to be raised. On the other hand, the total sum realized from subscriptions for the year amounted to only £1,207 5s. 6d., showing a deficit of £111 1s. 11d.

Mr. Robert McLaren, M.P., was unanimously re-elected President for the ensuing year.

THE MINING INSTITUTE OF SCOTLAND: ABSTRACT OF TREASURER'S ACCOUNT FOR THE YEAR 1920-1921.

INCOME.

	£ s. d.	£ s. d.
To Balance from year 1919-1920		216 2 8
,, Members' subscriptions—		
Arrears	17 19 0	
Current subscriptions	1,189 6 6	
Subscriptions paid in advance ...	65 5 6	
Life-members	70 0 0	
		1,342 11 0
,, Bank and investment interest		58 18 6
,, Income-tax refunded		7 4 0
,, Donation—Mr. Wallace Thorneycroft ...		10 0 0
,, Sundry receipts		0 12 2
		£1,635 8 4

EXPENDITURE.

	£ s. d.	£ s. d.
By Printing and stationery		115 9 9
,, Books and bookbinding		19 5 11
,, Rents		51 16 0
,, Salaries		182 12 0
,, Stamps, carriages, telegrams, etc. ...		25 10 5
,, Sundry payments		7 1 3
,, The Institution of Mining Engineers, calls, etc.		841 3 0
,, Expenses of representatives on the Council of The Institution of Mining Engineers		75 8 3
,, Balance—		
Cash in Post-office Savings Bank ...	31 10 8	
,, Invested in 2½-per-cent. Consols ...	80 15 0	
,, in Clydesdale Bank on deposit receipt	200 0 0	
,, Do. current account	4 3 9	
,, in Treasurer's hands	0 12 4	
		317 1 9
		£1,635 8 4

CAPITAL ACCOUNT.

	£ s. d.	£ s. d.
To Balance from year 1919-1920	1,155 18 0	
By Balance, invested as under:—		
£800 North British Railway 3-per-cent. Debenture Stock		582 2 0
£500 5-per-cent. War Stock, 1929-1947		473 16 0
£100 5-per-cent. National War Bonds, 1929 ...		100 0 0
	£1,155 18 0	£1,155 18 0

Examined, compared with vouchers, and found correct.

GLASGOW, *March 31st*, 1921.

GEORGE M. CHALMERS,
ANDREW H. TELFER, } AUDITORS.

THE "BEAM" ELECTRIC HEAD-LAMP.

By WILLIAM McNAUGHT.

The lamp, which has been experimented with for $2\frac{1}{2}$ years, and which provides an illumination equal to 2 candle-power, has a cell capable of supplying current for 18 hours, and is non-spillable. Everything about the lamp is perfectly clean, and the locking arrangements are so devised

Fig. 1.—Back View of "Beam" Electric Head-lamp as Worn.

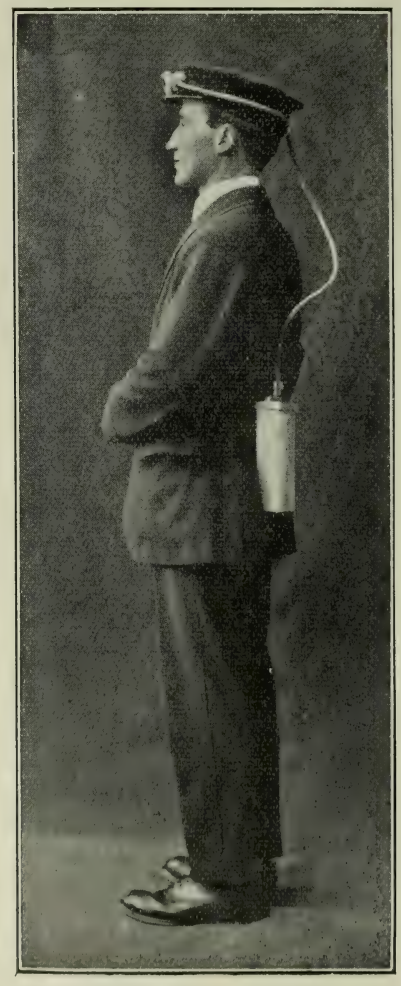

Fig. 2.—Side View of "Beam" Electric Head-lamp as Worn.

that there can be absolutely no tampering on the part of ordinary workmen. The weight of the lamp proper is $3\frac{1}{2}$ ozs., and with full attachments is 4 pounds, or 2 pounds less than the "Ceag." For the last two years I have worked personally with the lamp, and under a

variety of conditions it has given complete satisfaction. For repair work—even in the haulage roads—I have found it highly satisfactory. Both machinemen and haulagemen who have used the lamp are fully satisfied with it, and the Home Office has signified its approval of it.

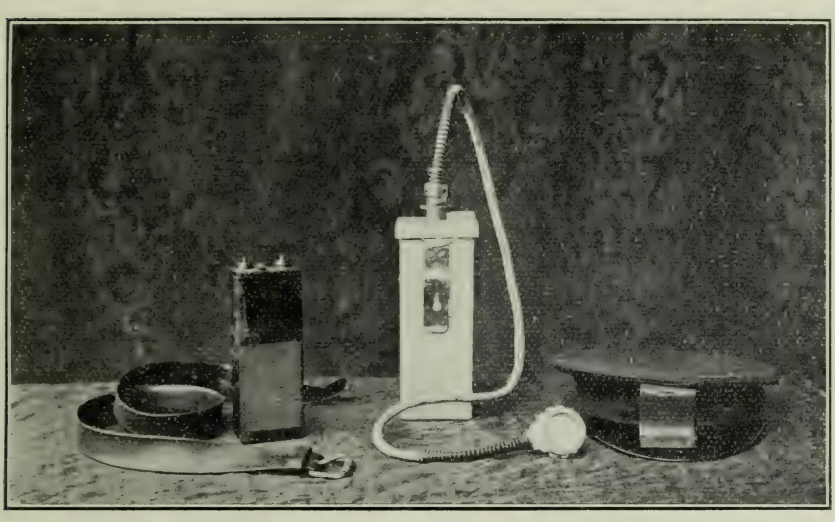

Fig. 3.—Details of "Beam" Electric Head-lamp.

which means that it can be used in any mine after permission has been granted by the Inspector of Mines for the district. The price of the lamp has not yet been fixed. At Girvan, where it is in daily use, those using it are satisfied that the cost of maintenance is not any greater than that incurred in the use of other electric lamps.

Sale of Transactions.

Copies of Vols. I. to LIX. (lacking Vols. XXXVIII. and XXXIX., which are now out of print) of the *Transactions* of The Institution of Mining Engineers will be supplied to Members only, to complete their sets, in paper covers, for £38 0s.; and single volumes can be supplied at the following rates:—Vols. I. and XLI. at £2 each; Vols. II. and III. at £1 5s. each; Vols. IV. to XXIII., XXVI. to XXIX., XXXII., XXXIII., XXXV., and XLII. to LIX., at 10s. each; Vols. XXIV., XXV., XXXI., XXXIV., XXXVI., and XXXVII., at £1 each; Vols. XXX. and XL., at £1 10s. each; duplicate volumes for any year (with the above exceptions), can only be supplied at £3 each year; postage in addition in each case. To Non-Members, Vols. I., II., III., and XLI., at £3 12s. each, and Vols. IV. to XXXVII., XL., and XLII. to LIX. at £1 16s. each; postage in addition. Bound copies will be supplied if desired.

Formation of a Library.

The Council will be pleased to receive books on mining, etc., or sets of *Proceedings* of any of the engineering societies, for the Library, as the want of suitable works of reference is greatly felt in connexion with the editing of the *Transactions*.

The Library is specially in want of the following publications:—

British Association for the Advancement of Science: *Annual Reports*, 1st to 12th, 18th, 32nd, 39th to 48th, and 50th.
British Society of Mining Students: *Criterion*, Nos. 1 to 10, 1876-1877.
Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers: *Transactions*, Vol. II., Parts 1 and 4; and Vol. III., Parts 3 and 4.
Cleveland Engineering Society (U.S.A.): *Journal*, Vols. I. to VI.
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Geological Magazine: Vol. I. to date.
Geological Society of London: *Quarterly Journal*, Vols. I. to III.
Geologists' Association: *Proceedings*, Vols. I. to VII., and XXI. to XXV.
Institution of Civil Engineers: *Transactions*, Vol. III., Parts 2, 4, and 5; and *Proceedings*, Vols. I. to. XX.
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Iron and Steel Institute: *Transactions*, Vol. I. (1869-1870); *Journal*, 1871, Nos. 1 to 4; 1872, Nos. 1 (Parts 1 and 2) to 4; 1873, No. 2; 1874, No. 2; and 1903, No. 1.
Manchester Geological Society: *Transactions*, Vols. I. to XII., XIV. to XVII., and XXII. to XXVI.
Midland Institute of Mining Engineers: *Transactions*, Vol. II., Part 14.
Mining Institute of Scotland: *Transactions*, Vols. I. and III. to VII. inclusive.
North of England Institute of Mining and Mechanical Engineers: *Transactions*, Vols. III. and IV.
Reports of Royal Commissions on Mines.
South Wales Institute of Engineers: *Proceedings*, Vol. IV., No. 3.
Yorkshire Geological and Polytechnic Society, *Proceedings*, Vols. I. to V., and XVII. to date.

All communications respecting the above should be addressed to the Secretary, The Institution of Mining Engineers, Albany Buildings, 39, Victoria Street, Westminster, London, S.W. 1.

SUBJECT-MATTER AND AUTHORS' INDICES

TO THE

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Volumes I. to XXX. (1889-1905), Royal 8vo., xv and 116 pages. Price to Members, 5s., or post free, 5s. 3d.; to others, 12s., or post free, 12s. 3d.

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Volumes XLI. to LV. (1911-1918), Royal 8vo., viii and 84 pages. Price to Members, 2s. 6d., or post free, 2s. 9d.; to others, 6s., or post free, 6s. 3d.

[34

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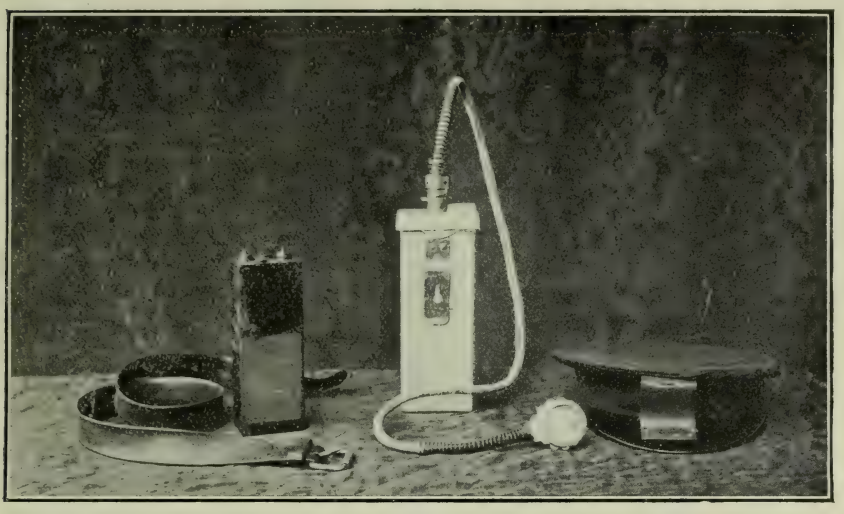

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THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,

Held in the Rooms of the Society, Queen's Chambers, 5, John Dalton Street, Manchester, April 12th, 1921.

Mr. VINCENT BRAMALL, President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were elected :—

Associate Members—

Mr. Arthur Grounds, Sun Fuel Company, Limited, North Dock, Swansea.
Mr. Samuel Jobling, 12, Towneley Terrace, Cliviger, Burnley.
Mr. Oswald John Onions, 33, Lily Lane, Bamfurlong, Wigan.
Mr. Arthur Tunnicliff, Bromfield Villa, Wrexham Road, Mold.

Associates—

Mr. Jacob Thomas Morgan, Glasfryn, Nelson, Cardiff.
Mr. John Sephton, The Cottage, Coach Road, Bickerstaffe, Ormskirk.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS, 5, JOHN DALTON STREET, MANCHESTER, MAY 10TH, 1921.

MR. VINCENT BRAMALL, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentleman, having been duly nominated, was elected :—

ASSOCIATE MEMBER —
Mr. THOMAS JAMES YORATH, Maesyrhaf, King's Hill, Hengoed, Cardiff.

WRONGFUL POSSESSION AND ABSTRACTION OF MINERALS.

BY DAVID BOWEN, BARRISTER-AT-LAW, F.G.S., F.S.I.

I.—INTRODUCTION.

It is unnecessary to emphasize the fact that in a fully-developed coal-field questions of wrongful abstraction of minerals frequently arise. In general the wrong is committed under mistake as to boundaries, and is not due to malice. In this paper it is not proposed to cover the whole ground which, from a legal point of view, may be included within the title of the paper, but to confine the discussion to such practical points as are of direct interest to mine-owners and mining engineers.

When one person makes an unwarrantable entry upon the land of another, the act of entry is an actionable wrong. For our general purpose it is not necessary to consider any of the fine distinctions as to what form of action lies in such a case; but the question is of some importance in pleadings if an action at law is contemplated and initiated. Before the abolition of the old forms of action, a knowledge of these distinctions was essential. The nature of the remedy available at law was the best explanation of the right violated.

Minerals *in situ* constitute land in the strict legal sense, and a person entitled to such minerals may therefore maintain an action against any one interfering with his right. The wrong usually committed in respect of minerals *in situ* is something more than mere trespass: entry itself is all that is necessary to constitute trespass; so that when minerals are wrongfully severed and appropriated by the wrongdoer, although in common parlance the wrong is often spoken of as an "underground trespass," the act of appropriating the severed minerals may entitle the rightful owner to a choice among several remedies.

In the majority of cases of wrongful abstraction, apart from the question of ascertaining true boundaries between adjoining properties, no difficulty is presented. In some cases, however, the circumstances may be so complex that no remedy is available to the injured party. A

great deal depends on the exact circumstances and facts of the case. But it will be interesting to consider three kinds of cases which sometimes present considerable difficulty, namely:—(*a*) Where the mineral is in solution, as in the case of brine; (*b*) where the mineral is more or less in suspension, or alternatively is so impregnated with water as to constitute running silt; and (*c*) where the mineral is in a more or less plastic or fluid state.

(*a*) *Mineral in Solution.*—As an instance of this type of case we may consider the case of Salt Union *v.* Brunner Mond (1906, 2 K.B. 822). Salt-mining and brine-pumping have been carried on in Cheshire for many generations. In the Northwich district the salt-rock consists of two beds; the top bed is found at a depth of from 47 to 100 feet below Ordnance Datum, and is about 80 feet thick. Below this bed is a thickness of about 30 feet of marl and marlstone, and underlying this is the lower bed of salt-rock, about 80 feet in thickness also. Prior to 1835 this salt was obtained in two ways—(1) by sinking a shaft down to the top of the upper bed and, if the rock-head was found to be wet, pumping up what was called "natural" or rock-head brine—that is, water impregnated with dissolved salt-rock; and (2) by dry mining in the ordinary way. During the latter half of the nineteenth century a third method of mining had become common in the district, namely, pumping brine from mines which had become inundated by water owing to the collapse of the roof and general subsidence of the ground and the consequent percolation of surface water down to the salt-rock. From 1838 onwards, in the district in question, owing to the increase in working in the dry mines and to other causes which need not be considered, but which were important in their results, the roof of some of the dry mines collapsed, some in the upper bed and some in the lower bed. The mines became flooded, and large areas of water of considerable depth were formed upon the surface, due to subsidence. The water thus percolating down to the salt-beds became impregnated with mineral in solution, and was pumped up as brine through shafts old and new. It was proved and admitted that these mines were connected together by underground passages—some originally made for purposes of ventilation—which naturally became what are known as underground brine-runs. It was impossible to pump brine from any one part of the area without disturbing the equilibrium of brine- or water-pressure.

It was argued that any contrivance by which one person takes away the rock-salt of another, whether it be by means of a pick-axe or a pump, is equally wrongful, and that there is no difference in principle between mineral in suspension (as in the case of silt) and mineral in solution (as in the case of brine). As will be seen later, it has been held that the rule that a landowner has no common-law right to the support of subterranean water does not apply to silt, and it was, therefore, argued that that decision would cover the case of mineral in solution instead of in suspension.

Per contra, it was argued that the distinction between water and brine is one of degree only, not of kind: for all water contains a certain amount of salt. The difference, however, between water and running silt is one of kind: the silt may be only wet sand, and the proportion of sand may preponderate over the proportion of water.

The position in such a case is then one of extreme difficulty. A shaft lawfully put down through a man's freehold may reach some underground channel or cavity from which he may pump brine, the real source of which it is impossible to predict, although it may be possible

after the event, by tracing subsequent subsidences, to form a judgment as to the area from which the salt-rock had been dissolved. To such an abnormal case it is practically impossible to apply the ordinary principles of law relating to underground property. That they cannot be applied in the matter of subsidences has been recognized by the legislature by the passing of the Brine Pumping (Compensation for Subsidence) Act, 1891. When a man puts down a shaft and pumps in his own land (both of which acts are *prima facie* lawful) the act does not of necessity become unlawful simply because it turns out that the brine thereby obtained may be the result of dissolution of rock in another man's property. Each case must depend upon its own circumstances.

(*b*) *Mineral more or less in Suspension.*—The leading case on this subject in this country is that of Jordeson *v.* Sutton, Southcoates, and Drypool Gas Company (1899, 2 Ch. 217). This case was one of support, but the evidence and arguments put to the court are of some importance, as this case may be distinguished from the one we have just considered and the third type of case to be considered presently. Under their statutory powers the defendants proceeded to excavate their land for the purpose of erecting a gasometer. In so doing they penetrated an underground stratum of quicksand, or sand loaded with stagnant water, known to geologists as "running silt," which extended under the plaintiff's land as well as under their own. The silt or sand largely preponderated over the water. In draining their excavation, notwithstanding all precautions against the inflow of the water and silt, the defendants withdrew a large quantity of the running silt from under the plaintiff's land, and thus caused a subsidence of the surface, with consequent structural injury to his houses.

The evidence was, apparently, conflicting on the question of how far the running silt was liquid rather than solid—as to whether it could be termed "mineral in suspension" as distinguished from wet mineral. Assuming that an action will not lie for damage caused by pumping water only, if in any particular case it is proved that what is pumped away is "mineral in suspension," practically indistinguishable from water, the case might conceivably approximate to the case of Salt Union *v.* Brunner Mond, *supra*, and the owner might be left without a remedy. Where, however, it is shown that what is pumped or withdrawn is not mineral in suspension but is really wet mineral, the proportion of mineral preponderating over the proportion of water, then the case approximates to the third type to be considered next. In an American case on the same subject, that of Cabot *v.* Kingman (166 Mass. Rep. 405), Field, C.J., said:—

"Whatever may be true of percolating waters, we think the defendants had no right to take away the soil of the plaintiffs in land which they had not taken under the statutes, and that it is immaterial that the soil was removed by means of pumps from the trench into which it had fallen by its own weight, or had been carried by percolating water."

(*c*) *Mineral more or less Plastic or Fluid.*—The first case of this type it will be convenient to consider is that of Trinidad Asphalt Company *v.* Ambard (1899, App. Case 594). In the district in question the pitch, the subject-matter in this case, lies at a depth of from 4 to 7 feet. So long as it is undisturbed it is stable and firm enough to support the overlying soil. But if an excavation is made and the stratum of pitch is cut through, the edge exposed to the atmosphere begins to melt and the pitch oozes out. According to one witness in the case, the plan adopted

when one wanted to dig one's neighbour's pitch was to dig right up to the neighbour's boundary, so that the neighbour's pitch oozed out on to one's land and was so "won." It was argued that pitch at a certain temperature becomes fluid, and in that state its behaviour is like water or any other fluid, and in the local Court it was inferred by one of the judges that consequently this underground stratum of pitch is no man's property until it has been appropriated, so that anybody and everybody who owned a lot in the district in question might with impunity win the pitch lying under his neighbour's land. On appeal, however, the fact that pitch is a "mineral," and not water, was held to distinguish the case from the cases in which underground water is drained away, and that the defendants were liable for the value of the pitch appropriated by them and for injury due to subsidence of the plaintiff's surface.

As distinguished from this case, we may consider the cases of minerals naturally fluid—for example, natural gas and petroleum. There are no decisions upon this type of case in this country, but there are several in the United States. There, although gas and petroleum have been held to be minerals, the decisions governing ordinary minerals apply to them only with several qualifications, and they are governed by rules analogous to those governing water percolating beneath the surface. Consequently, natural gas is not subject to absolute ownership: it belongs to the owner of the land, and forms a part of it so long as it is on the land and subject to his control; but when it escapes and goes into other land or comes under the control of another person, the title of the former owner is lost. Possession of the land is not necessarily possession of the gas. The same remarks apply to petroleum.

The question of the right to possession arises very frequently. Possession, in relation to minerals particularly, is in each case a question of fact or degree; it involves the intention to possess and the exercise of control over the land to the exclusion of other persons, such control being of that character of which the land is capable. Thus evidence of working under one part of the surface is *prima facie* evidence of possession of the whole land demised: but since coal-seams are generally continuous over large areas, a man who works part of such a seam does not thereby acquire *de facto* possession of the whole seam, although, apparently, even a wrongdoer may, by driving levels through a seam of coal acquire possession of the unworked coal within the limits to which the levels extend.

II.—Measure of Damages.

If the wrongful act consists of a mere entry—a user of the soil by passing over it without doing any damage—the damages in such a case are nominal only. There is no case to be found in which a trespasser having wrongfully used a way above ground has been made to pay compensation upon the basis of the benefit which has thereby accrued to himself. A claim for compensation in such a case cannot be made under the head of an account of profits, for the benefit arising from the use of an easement, even though it involve the saving of expense to the wrongdoer, is not a profit in that sense of the term. And it would seem that the case of such user in mines underground forms no exception. For instance, where the plaintiff owned a plot of ground so small that he could not profitably have worked the underlying coal himself and the defendant wrongfully worked the plaintiff's coal and subsequently carried other coal over the underground ways he had made under the plaintiff's land, Lord Hatherley considered that the plaintiff was entitled only to the value of the coal wrongfully worked, and not to any com-

pensation by way of wayleave rent in respect of the carriage of the other coal over his land (Livingstone *v.* Rawyards Coal Company, 1880, 5 App. Case 25).

If, on the other hand, the wrongful user of an easement has been productive of damage to the soil, as, for instance, where the owner of two portions of a coalfield has wrongfully and to save himself expense carried his coal from one portion to the other over the underground passages of an intervening mine of the plaintiff, and in so doing has damaged the passages and thereby increased the plaintiff's difficulty in getting his own coal, the Court has sometimes by way of compensation decreed an enquiry into the sum which the defendant would presumably have been willing to pay for the right to enjoy the easement, proceeding apparently on the assumption that the benefit accruing to the defendant from the user is proportional to the damage caused thereby to the plaintiff's mine (Jegon *v.* Vivian, 1874, 6 Ch. App. 742; and Phillips *v.* Homfray, 1871, 6 Ch. App. 770).

A third class of cases, and the most important generally, is that in which there has been a wrongful taking of another's minerals. In such cases the measure of damage is the value of the severed minerals as at the pit's mouth at the time of severance, allowances being made in respect of expenses incurred by the wrongdoer. In making such allowances either one of two rules is adopted. If the wrong has been committed innocently, the *milder rule* is applied, and the wrongdoer is allowed to deduct from the market value of the mineral at the pit's mouth the cost of severing and bringing the minerals to bank. If the wrong has been committed wilfully, the *harsher rule* is applied, and the only deduction allowed is the cost of bringing to bank, and not the cost of severance.

The latter rule was laid down in the case of Martin *v.* Porter (1839, 5 M. & W. 352) and followed in Morgan *v.* Powell (1842, 3 Q.B. 279; and Wild *v.* Holt, 1842, 9 M. & W. 672). It was based upon a technical rule of the common law that when something that was part of the realty —for example, coal—is severed from the realty and converted into a chattel, then instantly on its becoming a chattel it becomes the property of the person from whose land it was taken; and accordingly in estimating the damages against a person who had carried away that chattel it was considered and decided that the owner of the land was to be paid the value of the chattel at the time when it was converted into a chattel. No allowance was made for the expense of severing; it would, in fact, have been improper, as qualifying the wrong, to allow the wrongdoer anything for the expense which he had incurred in converting the rock into a chattel, an act which he had no right to do.

The milder rule was a qualification of the harsher rule, and was introduced in the case of Wood *v.* Morewood (1841, 3 Q.B. 440n.), an action in trover for coal worked under a claim of title. It was laid down in that case that if the wrongdoer was not guilty of fraud or negligence, but acted fairly and honestly in the full belief that he had a right to do what he did, compensation might be given, not for the value of the coal when it first existed as a chattel, but at its fair value to the injured party while it still remained part of the land.

Thus, where the wrong has been committed inadvertently, or under a *bona-fide* belief of title, or fairly and honestly, or in a case of mere mistake, or under a *bona-fide* expectation of a contract which the owner knew would be acted on at once, the milder rule is applied; and this rule also applies to cases where the mineral-owner stands by and sees the minerals worked without interfering (see generally the cases of Hilton *v.*

Woods, 1867 4 Eq. 432; Jegon *v.* Vivian, 1871. 6 Ch. App. 742; Elias *v.* Griffith, 1878, 8 Ch. D. 521; Ashton *v.* Stock, 1877, 6 Ch. D. 719; *re* United Merthyr Collieries, 1873, 15 Eq. 46; and Trotter *v.* Maclean, 1880, 13 Ch. D. 574).

The principle thus adopted is that if the wrongful act is shown to have been committed inadvertently, and there are no circumstances which a court of equity would consider to affect the case, just allowance is to be made for outlay on the part of the wrongdoer, and as far as possible there is to be returned to the rightful owner the full value of that which cannot be restored to him in *specie* (see Livingstone *v.* Rawyards Coal Company, 1880, 5 App. Cases 25). The owner has no right to follow the severed minerals into whatever place they may be carried, or in whatever circumstances they may come to be disposed of, and to fasten upon any increment of value which from exceptional circumstances may be found to attach to these minerals. The test is what may fairly be said to have been the value of the mineral to the person from whose property it was taken at the time when it was taken. In such cases the value is estimated upon the basis that no impediment exists which would prevent the owner from himself working the minerals. Where such an impediment exists, account may be taken of it; for instance, where the minerals could only have been worked by the trespasser, or the owner himself could not have worked them, damages are assessable upon the basis of the royalties customarily paid in the district.

Where the wrongdoer has acted fraudulently, or negligently, or wilfully, or in a manner wholly unauthorized and unlawful, the harsher rule is applied. Thus this rule was applied where the defendants had with permission driven headings into an adjoining mine during negotiations for a lease, and had continued the workings after they had declined to accept a lease; and where after preliminary workings in expectation of a lease it was found that the intending lessor had no power to grant a lease; and where the defendant worked a neighbouring mine with full knowledge as to his own boundaries; and even in a case of inadvertent working. In this last case (Ecclesiastical Commissioners (England) *v.* North-Eastern Railway Company, 1874, 4 Ch. D. 845), the ground of the decision seems to have been that, although there was no moral fraud—no fraud in fact—yet "for the purposes of the Statute of Limitations the breaking of bounds into a neighbour's colliery must be considered a fraudulent act." There is no foundation for such a proposition. Underground trespass may be committed in good faith without any sinister intention, or it may be committed in circumstances which would render the wrongdoer liable to a prosecution for felony. Every case must depend on its own circumstances (see generally Joicey *v.* Dickinson, 1881, 45 L.T. (N.S.) 643; Bulli Coal Company *v.* Osborne, 1899, App. Cases 351 P.C.; Llynfi Coal Company *v.* Brogden, 1871, 11 Eq. 188; and Phillips *v.* Homfray, 1871, 6 Ch. App. 770).

It has been said that the mere conscious violation of the owner's right itself amounts to fraud (see Ashton *v.* Stock, 1877, 6 Ch. D. 726); and it has also been said that an underground trespass, even though innocently committed, must be considered to be a concealed fraud; but this latter *dictum* does not accord with other authorities.

To amount to a fraud within the meaning of the Statute 3 and 4, Will. 4, C.27, S.26, the act must be done neither by inadvertence nor under a *bona-fide* belief of title (see *re* Astley & Tyldesley, etc., Company, 1899, 68 L.J.Q.B. 252). The onus of proof in respect of such belief must lie on the party setting it up, for every secret underground trespass

is *prima facie* fraudulent. The milder rule will, however, now be applied, subject to any case made of a special character which would induce the court to depart from it.

III.—Effect of Statutes of Limitations.

Under the Real Property Limitation Acts of 1833 and 1874 a wrongdoer may acquire a title to mines by entry and possession over a period of twelve years. The title acquired is limited in general to the portion of the mine actually occupied or worked. It is a question of fact whether possession has been taken of the whole mine, but possession of one seam of coal is not conclusive evidence of possession of all the seams which lie beneath. Moreover, if a trespasser abandons possession before he has acquired a title, time does not run in his favour although there is no new act of ownership by the rightful owner (see Dartmouth *v.* Spittle, 1871, 19 W.R. 444; and Glyn *v.* Howell, 1909, 1 Ch. 666).

If a title is thus acquired by adverse possession, no action may be maintained for the value of the minerals removed; but independently of such adverse title the injured party's right to recover may be barred by lapse of time. Thus, a claim for compensation in respect of minerals wrongfully abstracted will be barred, in general, if the abstraction has taken place more than six years before the action was brought; and it follows that where minerals have been gotten partly within and partly before that period an account will, in the absence of fraud, be limited to the minerals worked during the statutory period of six years. If the trespass is inadvertent, it is immaterial that the injured party was ignorant of the wrong done to him where there has been no active concealment on the part of the wrongdoer. But there may be circumstances in which an account will not be limited to the minerals gotten within the period of six years, as in the case of concealed fraud and where the injured party through no fault of his own has remained in ignorance of the abstraction. The owner's ignorance of his right of action may result either from his ignorance of the existence of his title or from his ignorance of the fact of the other party's wrongful acts. Where the necessary conditions of wilful and secret trespass on the part of the wrongdoer, and ignorance coupled with the absence of laches on the part of the injured party, are fulfilled, nothing more is necessary to establish the existence of a concealed fraud which will prevent the operation of the Statute of Limitations, in which case the account will not be limited to a period of six years. It is important to note that the mere neglect to make surveys is not fraud which will oust the operation of the Statute.

In concluding this general outline of the law as to wrongful abstraction of minerals, it is necessary once more to emphasize the fact that while what has been here written may serve as a statement of general principles, every individual case that arises possesses some peculiarities of its own, and must to a large extent depend upon its own facts. Occasionally these facts are very complex, either from the extreme doubt as to the source of the minerals, as in the case of Salt Union *v.* Brunner Mond, or as to the ownership of the minerals, as happens when there is a dispute as to boundaries. An action of trespass is often a convenient mode of action for determining the title to mines. The questions that arise as to admissible evidence in such cases, although of great interest to mining experts who are called as expert witnesses to assist in coming to a decision as to facts, are questions that frequently vary in individual cases, and it would be inadvisable to consider them in this paper.

The PRESIDENT (Mr. Vincent Bramall): I thought that when minerals were wrongfully extracted it was not necessary to prove fraud. In the case of a man who, through gross carelessness, entered into another person's land and worked his mine, I was of opinion that the date at which proceedings might be commenced was the date when the act was discovered.

Mr. J. DRUMMOND PATON (Manchester): With regard to the ordinary mine lease, is there any source from which information in relation to trespass can be obtained, or is there any proposal to the effect that all the leases should be registered? Should not all existing leases be certified and registered at Somerset House, so that in the case of an alleged trespass it would be easy to obtain information without having to fight the matter in the law-courts? Can Mr. Bowen suggest a basis for such a measure?

The PRESIDENT: I am afraid that if we had to keep all our working-plans posted to date, and have them registered at Somerset House, it would mean engaging a number of additional officials.

Mr. DRUMMOND PATON: I think that the cost would be less than the amount now spent in fighting cases.

The PRESIDENT: It would mean that a copy of all mine plans would have to be kept at Somerset House, and kept up to date, which would entail considerable labour and expense. We had a peculiar mortgage case some time ago in which we agreed to purchase the coal under a few cottages. The agent who acted for the estate sold it, but the owner said that he had no right to sell it. Under threat of an action, we finally bought the property. In another case a leading counsel advised us we had a right to work, and that the sale to us gave us full rights to work. He was subsequently made a judge, the case actually came before him for trial, and, strange to say, he found against us.

Mr. DAVID BOWEN (London): Reference has been made to gross carelessness. In such a case the general rule is that gross carelessness in the working of a mine includes indifference as to whether a trespass is committed or not. In such a case as that I should say that the Statute of Limitations would not apply, and damages could be obtained extending over the whole period of trespass.

As to the suggestion that leases should be registered or deposited at Somerset House, I would point out that whenever any company either purchases land or takes a lease of land, the property and boundaries are always described in the recital or opening part of the deed, and are delineated on the plan attached. If a man when taking a lease agrees to pay so much minimum rent every year, or even pays down a lump sum, he will surely ascertain, in order to make absolutely certain, what his boundaries are. If he knows that there are adjoining minerals being worked by neighbouring owners, it is to their mutual interest if there is any suspicion of a trespass that they should come to some agreement between themselves. He should be allowed to go down the other's mine to ascertain whether his suspicion is well founded or not. If a mine-owner will not allow his neighbour to go down his particular mine in order to obtain that information, all that is required to be done is to take out a summons in the High Court. One can apply simply on the ground of suspicion provided that a *prima-facie* case is made out sufficient for an order for the inspection of a neighbour's property. That order for inspection would

include the right for the applicant to go down his neighbour's shaft, together with the necessary assistance from him, or from his deputies and workmen, to reach the point where it is suspected that the boundary has been transgressed. If any obstacle whatever is put in the way, the order will include the right to have that obstacle removed so far as it is necessary for the purpose of the applicant, and so far as it will not endanger his neighbour's mine. If that inspection underground is not sufficient to decide the point, there can be included in the same order the right to inspect the neighbour's title-deeds and plans. From an inspection of those deeds it can be ascertained what his boundary is; and if there appears to be any overlapping of boundaries, then something is wrong. The person who sold the land or granted the lease either had or had not the right to grant the particular area in dispute; and if one is satisfied on the latter point, the neighbour has got more land than he is entitled to. On questions like that the mere fact of depositing plans or leases at Somerset House would not settle the problem. In fact, under the Coal Mines Act of 1911, one is bound to submit plans to the Mines Department of the Board of Trade, particularly of abandoned workings. But quite apart from that, it is to your own interest to keep plans, particularly as you are usually bound in the case of a lease to make quarterly surveys, and under the Act you are also bound to do that, so that as a matter of fact plans of your underground workings are being constantly kept up to date.

In the case of a sale outright, it very often happens that a man thinks that he possesses more property than he really owns; or he may own the property as a limited owner, and grant a lease for a longer period than he has power to do. The person who grants the lease, however, cannot dispute the deed under which he has granted the lease, and the deed exists as a sort of first-class legal evidence against any repudiation by him of the lease. He cannot repudiate the lease on the ground that he had no power to grant it; he may be liable to be ordered specifically to perform his contract and to pay damages for the part he is unable to perform. As to the position of the lessee, that is a different matter, and depends on the facts of the case—whether the lessee had any knowledge that the tenant or owner could not grant what he presumed he could grant.

With reference to the case cited by the President of counsel who advised that certain coal could be worked, and when he tried the case as a judge decided against the people he had previously advised, there is a simple explanation for this. As often happens, he might be a very busy counsel and not look at the case himself; he might have trusted the matter to his "devil." On the other hand, it might be that the facts put to him for his opinion were not as full and detailed as when the case was tried in court. There are two sides to every case, and counsel when giving an opinion knows only one side, whereas when sitting as a judge both sides are submitted to him.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,

HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE, JUNE 4TH, 1921.

LT.-COL. F. R. SIMPSON, PRESIDENT, IN THE CHAIR.

OFFICERS AND COUNCIL, YEAR 1921-1922.

Mr. Charles Catterall Leach was unanimously nominated as President for the ensuing year.

The Assistant Secretary read the balloting-list drawn up by the Council, containing the names of officers for the year 1921-1922.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated :—

MEMBERS—

Mr. JOHN HENRY TATE, Lecturer in Mechanical Engineering, P.O. Box 52, Kalgoorlie, Western Australia.

Mr. HARRY WIDDAS, Electrical and Mechanical Engineer, 3, Roper's Terrace, Trimdon Grange, Trimdon Station, Co. Durham.

ASSOCIATES—

Mr. JOHN WILLIAM BARRASS, Master Shifter, 9, Woodhorn Colliery, Ashington, Northumberland.

Mr. JOHN BELL, Overman, Front Street, Dipton, Co. Durham.

Mr. JAMES BURRELL, Master Shifter, 2, Woodhorn Colliery, Ashington, Northumberland.

Mr. ALBERT CRAGGS, Overman, 7, Cross Row, Felling, Gateshead.

Mr. JOSEPH DAVISON, Fore-overman, 4, Woodhorn Colliery, Ashington, Northumberland.

Mr. RICHARD EAMES, Assistant Master Shifter, Linton Colliery, Ashington, Northumberland.

Mr. CHRISTOPHER GRAHAM, Back-overman, Linton Colliery, Ashington, Northumberland.

Mr. THOMAS HARDY, Engineer, Linton Colliery, Ashington, Northumberland.

Mr. JAMES TIMOTHY HERRON, Assistant Master Shifter, Linton Colliery, Ashington, Northumberland.

Mr. JOHN HODGSON, Coal Miner, 8, West Terrace, Waterhouses, Durham.

Mr. JOSEPH JONES, Fore-overman, 29, Double Row, New Delaval, Newcastle-upon-Tyne.

Mr. THOMAS MORAN, Back-overman, Edington Gardens, Clara Vale, Ryton, Co. Durham.

Mr. WILLIAM ROBSON, Master Shifter, 8, Cement Cottages, Hamsterley Colliery, Co. Durham.

Mr. GEORGE THOMAS SMITH, Colliery Under-manager, Victoria Garesfield, Rowlands Gill, Newcastle-upon-Tyne.

Mr. CHARLES THOMPSON, Colliery Under-manager, 5, Eden Terrace, Gilesgate Moor, Durham.

Mr. SYDNEY DOUGLAS THORPE, Assistant Colliery Manager, 11, New South View, Windlestone, Ferry Hill, Co. Durham.

Mr. ROBERT TURNER, Deputy Overman, 20, Edward Row, Hamsterley Colliery, Co. Durham.

Mr. JOSEPH WOOD, Powder Distributor, 4, First Row, Linton Colliery, Ashington, Northumberland.

Mr. WILLIAM SIMPSON WOOD, Electric Coal-cutting Machineman, 82½, Sycamore Street, Ashington, Northumberland.

STUDENTS—

Mr. ROBERT LAMBERTON NISBET, Mining Student, 26, Beverley Gardens, Cullercoats, Whitley Bay, Northumberland.

Mr. ARTHUR STANTON EDGCOME RICHARDS, Mining Student, The Vicarage, Maryport.

Mr. JOHN JOSEPH ROWE, Mining Student, Armstrong College, Newcastle-upon-Tyne.

Mr. ALGERNON WADE, Mining Student, 63, Long Row, Oakenshaw, Willington, Co. Durham.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,

HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS, 5, JOHN DALTON STREET, MANCHESTER, JUNE 14TH, 1921.

MR. G. B. HARRISON, PAST-PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentleman, having been duly nominated, was elected :—

ASSOCIATE MEMBER—

Mr. RICHIE BRINDLEY DAVIES, 58, High Street, Gilfach Goch, Bridgend.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM MAY 29TH TO JULY 2ND, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	May 29	1	21′·0	22′·5	18′·0	17′·0	17′·5	22′·5	25′·0	23′·0	22′·0	21′·0	21′·5	21′·5	21′·0
Mon. ..	30	0	20·5	19·5	18·5	16·5	17·5	21·5	25·0	24·0	22·5	21·0	21·0	21·0	20·5
Tues. ..	31	0	20·5	19·5	18·0	18·0	20·5	24·5	27·0	26·0	23·5	22·0	20·5	20·5	21·5
Wed. ..	June 1	0	20·0	19·0	17·5	16·5	16·5	20·0	24·0	24·0	21·5	21·0	21·5	21·5	20·0
Thur. ..	2	0	20·5	20·0	17·5	17·0	19·0	25·5	27·0	23·5	21·5	20·5	20·5	21·0	21·0
Fri. ..	3	0	20·0	19·0	17·5	15·5	17·5	21·5	24·0	24·0	22·5	22·0	22·0	20·5	20·5
Sat. ..	4	1	18·5	16·5	16·5	16·0	21·0	26·5	28·5	28·0	24·5	20·5	19·0	19·5	21·5
Sun. ..	5	0	19·5	17·5	17·0	16·5	18·5	22·0	25·0	23·5	21·0	20·0	20·0	20·5	20·0
Mon. ..	6	1	20·5	19·5	17·5	15·5	18·0	23·5	29·0	28·5	24·5	17·0	19·5	21.0	21·0
Tues. ..	7	0	20·0	19·5	20·0	18·5	18·0	23·5	29·0	28·5	23·5	20·5	19·5	20·5	21·5
Wed. ..	8	1	21·5	19·5	16·5	16·0	17·5	23·0	27·0	27·0	24·5	21·5	18·0	15·0	20·5
Thur. ..	9	1	18·5	22·0	17·0	15.0	16·0	21·5	27·0	28·0	25·5	21·0	20·0	20·5	21·0
Fri. ..	10	1	22·5	17·0	17·5	16·5	17·0	20·0	22·5	23·0	22·5	20·5	20·0	20·5	20·0
Sat. ..	11	0	20·5	19·0	16·5	16·0	17·5	21·0	23·5	23·5	22·0	21·0	20·5	20·5	20·0
Sun. ..	12	0	20·0	19·5	17·5	17·5	18·5	20·5	23·5	24·0	22·5	22·5	22·0	21·5	21·0
Mon. ..	13	0	20·5	20·5	17·5	15·0	16·0	20·0	24·0	24·5	24·0	22·0	21·0	20·5	20·5
Tues. ..	14	1	20·5	19·0	16·5	15·5	18·0	21·5	24·5	25·5	23·0	22·0	21·5	19·5	20·5
Wed. ..	15	0	17·5	18·5	18·5	17·0	19·0	22·0	24·0	24·0	21·0	20·0	20·0	20·0	20·0
Thur. ..	16	0	19·5	18·5	15·5	15·5	17·5	22·0	23·5	24·0	21·0	21·0	21·0	20·5	20·0
Fri. ..	17	0	20·5	21·5	19·5	18·0	19·5	23·5	27·5	26·5	22·5	20·5	20·5	21·0	21·5
Sat. ..	18	0	20·5	19·0	16·5	15·5	17·0	22·5	26·5	25·5	22·5	20·5	20·5	21·0	20·5
Sun. ..	19	0	20·0	19·0	17·5	16·0	17·5	21·0	24·0	25·5	23·5	21·5	20·0	20·5	20·5
Mon. ..	20	0	19·0	16·5	16·0	14·5	16·0	22·0	26·0	26·5	24·5	21·5	20·5	19·0	20·0
Tues. ..	21	0	18·0	17·5	17·5	17·0	16·0	18·0	23·0	24·0	21·5	20·0	18·5	19·5	19·5
Wed. ..	22	1	19·0	19·5	19·0	17·5	14·5	18·0	23·0	24·0	22·0	20·5	20·5	20·5	20·0
Thur. ..	23	0	19·5	18·5	17·0	13·5	13·0	20·0	26·5	28·5	26·5	23·0	20·5	21·0	20·5
Fri. ..	24	0	20·0	19·0	18·0	14·5	15·0	19·5	24·0	23·5	22·0	20·5	20·0	20·0	19·5
Sat. ..	25	0	19·0	18·5	17·5	16·5	16·0	19·5	23·0	23·5	23·0	20·5	20·0	20·0	20·0
Sun ..	26	0	18·5	18·5	18·0	16·0	17·0	20·5	25·5	26·5	24·0	21·5	20·0	19·5	20·5
Mon. ..	27	0	18·5	17·5	15·5	13·5	15·0	18·5	23·0	23·5	22·0	21·0	20·5	20·0	19·0
Tues. ..	28	0	19·5	18·5	16·0	14·5	15·0	19·0	22·0	21·0	20·5	20·0	20·5	20·5	19·0
Wed. ..	29	1	21·0	19·5	16·5	13·0	13·5	18·0	24·0	24·5	22·0	21·0	18·5	19·5	19·0
Thur. ..	30	0	19·0	17·5	15·5	16·0	16·5	21·0	23·5	23·0	20·5	20·0	20·0	18·5	19·0
Fri. ..	July 1	0	16·0	16·0	15·0	13·5	15·0	21·0	25·5	26·5	22·0	19·0	18·5	18·5	19·0
Sat. ..	2	0	17·5	17·5	15·0	13·0	14·0	19·5	23·0	22·0	20·0	19·5	19·5	19·5	18·5

Diurnal Inequality (i.e., departure from mean value for day).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
June, 1920	−1′·0	−1′·5	−2′·0	−2′·8	−4′·2	−4′·9	−5′·3	−4′·9	−3′·7	−1′·5	+1′·6	+4′·4
May, 1921	−0·8	−1·0	−1·0	−1·9	−2·5	−3·5	−4·4	−4·4	−3·3	−0·9	+1·9	+4·6
May, 1920	−0·9	−1·4	−1·7	−2·3	−3·2	−4·3	−4·4	−3·8	−2·3	+0·3	+2·8	+4·8

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
June, 1920	+6′·0	+6′·4	+5′·6	+4′·1	+2′·6	+1′·3	+0′·4	+0′·4	+0′·2	+0′·1	−0′·4	−0′·6
May, 1921	+5·6	+5·3	+4·2	+2·8	+1·9	+0·6	+0·2	−0·3	−0·8	−0·8	−0·7	−0·6
May, 1920	+5·7	+5·4	+4·1	+2·7	+1·5	+0·3	−0·2	−0·4	−0·4	−0·4	−0·9	−1·1

Mean Value for Month.

June, 1920.	May, 1921.	May, 1920.
14° 31′·0.	14° 21′·2.	14° 31′·9.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The above values were obtained from measurements made after "smoothing" the curves.

THE INSTITUTION OF MINING ENGINEERS.

GENERAL MEETING,
Held in the Rooms of the Geological Society, Burlington House, Piccadilly, London, W. 1, June 9th, 1921.

Mr. C. C. LEACH, Vice-President, in the Chair.

CO-OPERATION WITH THE INSTITUTION OF MINING AND METALLURGY.

The Chairman: I am very sorry to state that the President, Col. W. C. Blackett, is unable to be present to-day owing to unavoidable circumstances. I will ask Sir John Cadman, the Hon. Secretary, to make a statement with regard to the arrangements which are being made for closer co-operation between this Institution and The Institution of Mining and Metallurgy.

Sir John Cadman, K.C.M.G. (London): For some time past the Council has been considering questions connected with the development and future policy of the Institution, and discussions have taken place on the lines of getting into closer co-operation with The Institution of Mining and Metallurgy, particularly in regard to housing and general administration. Doubtless the members are aware that the lease of our premises at 39, Victoria Street, Westminster, will shortly terminate, and it therefore became necessary to consider the question of new accommodation and a general re-arrangement of the establishment to meet its present needs. After some discussion a communication was addressed to The Institution of Mining and Metallurgy asking if the two Councils could consider whether there was any way in which closer co-operation could be arrived at. As a result of this communication a discussion took place between Committees of the two Councils, and there at once appeared to be a unanimous opinion that in the best interests of the mining engineering profession and the interests of this Institution greater strength and advancement could be secured by a closer alliance between the two Institutions. The time was opportune for both Institutions to consider some joint housing scheme, for The Institution of Mining and Metallurgy had also under consideration a change in housing accommodation. That was not, however, the chief point of view which really weighed with the two Councils: it was a very definite and unanimous desire to bring the two Institutions into closer co-operation, particularly on matters of policy. As a result of these negotiations, the Council at its meeting in Leeds, on March 16th, after very lengthy and careful consideration, resolved that The Institution of Mining Engineers should be housed with The Institution of Mining and Metallurgy, that the office administration should be combined, that there should be one Secretary to the two Institutions, that the staffs should be amalgamated, and that the Libraries should be joined (the books, of course, remaining the property of each Institution). The financial arrangements will continue to be handled by the two Councils as at present, and the separate identity

of the two Institutions vigorously maintained. As the arrangements were of a business character, and did not involve any alteration of the Charter or Bye-laws, the Council did not find it necessary to consult the general body of the members.

The final arrangements were left to the two Presidents to confer and agree upon. This has now been done, and I am instructed to inform you that the Institution will move from its offices in Victoria Street to the house which The Institution of Mining and Metallurgy has acquired in City Road, that satisfactory financial arrangements have been made, that Mr. C. McDermid, the Secretary of The Institution of Mining and Metallurgy, has been appointed to be the Secretary of the Institution of Mining Engineers, that Mr. Percy Strzelecki will become Assistant to the Secretary, and that some of the senior members of the staff of this Institution will also be transferred. The general arrangement is that during the next two years the actual cost to the Institution will not be thereby increased, and that any change which may hereafter take place with regard to the administration expenses of the Institution will be in proportion to the existing expenses of the two Institutions.

The Council is of opinion that the arrangements which have been made are in every respect satisfactory. The way in which The Institution of Mining and Metallurgy has met The Institution of Mining Engineers has been in the most cordial spirit; their desire has been our desire—to increase the standing and efficiency of the mining engineering profession.

The Chairman: We have had a very clear statement from Sir John Cadman. A great deal of thought has been given to the matter by the Council; the proposal was very cordially received, and was passed by a unanimous vote. I beg to move the following resolution:—

"That the Members of The Institution of Mining Engineers hereby express their cordial approval of the working arrangements entered into with The Institution of Mining and Metallurgy, and resolve that a copy of this resolution be sent to that Institution, with an expression of their conviction that as the result of the closer co-operation of the two Institutions the interests of the profession of mining engineering will be strengthened and materially advanced."

This is the day of great combinations, and I think this is probably one of the greatest. It will not be used for selfish purposes, but to advance all that is best in both Institutions.

Mr. H. K. Scott (London): It was my privilege at the Annual Meeting of The Institution of Mining and Metallurgy, in proposing a vote of thanks to the Council and staff on behalf of the members, to confirm and approve the agreement which has been made between the two bodies. Like many others, I happen to be a member of both Institutions, and as it was my pleasure then to approve on behalf of the members, I am very pleased to have the opportunity of speaking here and approving also. The spirit in which this movement has been undertaken is, I think, a very happy augury for the future and for the working arrangements being carried out without friction. It is quite possible—and, indeed, I suppose in the nature of things it must be certain—that at some period, probably in the not far distant future, there may be some slight conflict of interests; but I think that any difficulties of that kind will be amicably arranged. The Chairman has referred to this being a day of combinations, but I hope that we shall never be accused of having formed a Trust. I hope that the movement which is now being carried out in such a happy manner will always enjoy the confidence of members of both Institutions. I beg to second the motion.

Mr. M. H. Mills (Folkestone): As one of the oldest members of the Institution, I feel that this matter has been rather sprung upon us. We have not had the information which we think we ought to have had before agreeing to so great a change as that of giving up to some extent our identity, because that is what it comes to. The constitution and bye-laws of The Institution of Mining and Metallurgy, to which society I belonged for some time, are quite different from our own; the work of that Institution is entirely different, and its members are different; and I feel that we shall lose some part of our old associations if we join them without more thought. I am not aware that we as members have had any information about this matter, and personally I feel that I should not like, on what I have just heard to-day, to agree to any such proposal.

Sir John Cadman: There is no change in the Institution. This is a mere business arrangement which the Council has very seriously considered, and in its view it is a step that will advance the interests of the Institution. The Council will function as before; the only difference is that the office which runs the business of the Institution will be the same office as that which runs the business of The Institution of Mining and Metallurgy. There are certain economies, but the great point is that the two Institutions, while working more or less in watertight compartments, and still functioning independently in the interests of their members, will be brought closer together. There will be a small Committee before whom questions of policy which concern both Institutions can be considered. The Institution is not in any way giving up its great traditions. I can assure you that that point was very jealously guarded by the Council when the matter came under consideration.

Mr. Robert McLaren, M.P. (Airdrie): One has much sympathy with Mr. Mills, because I think none of us wants our identity to be obliterated. Speaking personally, if I had for one moment thought that joining up in the way we have done with The Institution of Mining and Metallurgy was going to take away our identity, I certainly would have opposed the project. But it appears to me, as far as I can see, being a member of the Committee which has dealt with this important matter, that each Institution will function in its own way, and the one will not interfere with the other. As Sir John Cadman has stated, I think it is well on the broad principle of policy that these two Associations—which, after all, in very many respects represent mining—should be connected in some official manner in order to safeguard the interests of the mining engineers of this country. It has always been a source of sorrow to me that in all mining legislation there did not appear to be sufficient co-operation amongst the mining engineers of this country, and unfortunately when it became necessary to consult the mining profession in connexion with any mining legislation there was not any authoritative body to which the Government could appeal. The Miners' Federation of Great Britain could always be appealed to.

Now I think that in making the present arrangement we shall be able to direct public attention to the fact that behind these two Institutions there is a very large body of scientific and technical opinion which cannot be ignored in any legislation which may be considered in the future. I therefore welcome very heartily this new arrangement, knowing at the same time that while the arrangement is a good one our identity as mining engineers will not be in any way interfered with. Each of the Institutions will do its work separately.

I have very great pleasure in supporting the motion which has been moved from the Chair.

Mr. W. H. Patchell (London): I think Mr. McLaren has struck the right note. That unity is strength is an old saying, and never did we want it more than we do to-day. We have the South Wales Institution, we have our own, which is a federation of seven mining societies scattered all over the country, and we have also The Institution of Mining and Metallurgy. If those were all working together, they would command the influence which Mr. McLaren suggests. Personally, I should like to see things go very much further; I would like to see engineers as such get together in the way they have done on the other side of the Atlantic —I refer to the American Engineering Council—for we should then help the public and command the respect of the Houses of Parliament in a way that we do not now. I understand that the idea is not to fuse the two Institutions—at present, at any rate, and probably never; but the combination cannot but make for efficiency and for economy. Those of us who belong to three or four Institutions will be glad to see the co-operation established. I am very pleased to see these two Institutions coming together, and I hope that steps will be taken to bring in the smaller societies connected with mining. When they are affiliated in one large and strong Institution, they will command a respect which smaller bodies cannot and never will possess.

Mr. Theodore Stevens (U.S.A.): I should like to support the last speaker. There are a great many of us who are members of the American Institutes as well, and we know what co-operation means. I think that the sense of this meeting will probably be that it is wise to get all engineers as closely together as we can, while retaining the identity of each Institution.

Mr. M. H. Mills: I should like to make my position perfectly clear. I do not wish to appear to be opposing what has been suggested. My position is simply this—that I do not think that we have had matters put sufficiently clearly before us to pass a resolution giving the Council power to make any arrangements it may consider fit. I think that what has been arranged, or what is proposed to be arranged, should be carefully drawn up, printed, and circulated among the members and a meeting called to confirm the proposal. We have had no intimation of this change that I am aware of—it has been sprung upon us; this is a very small meeting, principally, I imagine, composed of Members of Council, and I think that we ought to have more time. In order to put myself in order, I will propose, whether I have a seconder or not, that the question of agreeing to this resolution be adjourned until the members have had time to consider the details of the scheme.

The Chairman: As a matter of fact, I think that you have taken a wrong view. All that the Council has done is to get another building, as the one occupied by the Institution at present will shortly have to be given up, and to have another Secretary. That is the long and short of it. I do not think it is necessary for the members to be asked to decide that question, because the members have appointed the Council.

Sir John Cadman: I do hope that Mr. Mills will not press the point which he has raised. The view which the Council has taken, after very deliberate consideration, is that unless this Institution, so far as its London office is concerned, is prepared to place itself in a position where

it can more closely be associated with mining problems generally, we are not going to advance at the rate and in the direction which is necessary in the interest of the profession as a whole. The Council in its judgment has come to a decision in the conduct of the Institution's business. It has not in any measure altered the constitution of the Institution; it has not in any direction affected the Charter or the Bye-laws; it has decided to make a change in the housing and administration. Such a decision is within the powers of the Council; but, in view of the fact that it is likely to have so far-reaching an effect, the President felt that he should report this matter to the members of the Institution at the meeting to-day, and I hope that the members present will give the Council their whole-hearted support.

The Chairman: I would like to assure Mr. Mills that when these proceedings were being discussed by the Council, we were not all of opinion that it would be the best thing for the Institution, but before we separated we were all of that opinion. I do hope that the vote will be unanimous.

Mr. M. H. Mills: I should like, if I may, just to say that the explanation which has been given is very clear. My only point is that I think we ought to have had more time as members to consider it. We may have complete confidence in our Council—personally, I certainly have—but, even so, it is one of those important matters in which I feel very strongly the members should have been consulted before such a change in the constitution of the Institution was made. In face, however, of what has been said, I am quite ready to withdraw the amendment which I proposed.

The motion was put by the Chairman and carried unanimously.

PRESIDENT-ELECT.

The Chairman: I have much pleasure in announcing that Prof. Sir John Cadman, K.C.M.G., has been nominated by the Council to be President for the ensuing year. He is so well known to everybody that I need only say that I do not think we could have selected a better man for the post.

THIRD REPORT OF THE COMMITTEE ON "THE CONTROL OF ATMOSPHERIC CONDITIONS IN HOT AND DEEP MINES."

I.—Introduction.

The following Report has been prepared for the Committee by Mr. J. P. Rees, who is also responsible for most of the actual observations. The deep pits in which the observations were carried out were selected partly on account of the depth of the workings and partly on account of specially adverse conditions which made it difficult to control the temperature. All of these pits were under the general management of individual members of the Committee.

The work was organized from the Doncaster Coal Owners' Laboratory, Bentley Colliery, as a base, and many preliminary observations, already alluded to in our first Report, were carried out at the Laboratory or in neighbouring pits by Messrs. J. Ivon Graham and J. T. Storrow. Mr. Graham has also co-operated in all the experiments detailed in the present Report. For the actual observations made at Bowhill Colliery, the Committee is indebted to Mr. T. T. Thyne, Surveyor to the colliery. The managers and other members of the staffs at Bowhill, Pendleton, Pendlebury, and Shelton Deep Pit have given invaluable help. A number of observations made at Bentley Colliery are also included, since they throw new and clear light on certain of the factors governing underground temperature; and the Committee is specially indebted to Mr. Robert Clive, Agent for Bentley Colliery, for his co-operation.

The object of the experiments was to investigate in detail the operation of causes leading to the existence of high underground temperatures, and particularly high wet-bulb temperatures. The determining factors are analysed and distinguished as far as practicable.

As was pointed out in the First Report, there are three causes for the rise of temperature in underground workings. The first is the heating due to compression of the air as it descends shafts or inclines (about 5·5° Fahr. per 1,000 feet of descent); the second is conduction of heat from surrounding strata; and the third is formation of heat in the oxidation of coal, or other minerals, and timber. The increase in the moisture contained in the air is due to evaporation of the water which percolates through the walls of shafts and roads, or is present in freshly-exposed coal or other material. The heat and moisture given off from men, horses, and lamps is scarcely appreciable in a coal-mine. Heating by compression cannot be obviated, except at the expense of evaporation; but it can be, and to a large extent always is, averaged over the year in the actual workings of a mine, the walls of the shaft and roads giving off more or less heat to the air according as the external temperature is lower or higher. In exceptionally warm weather the walls may even take up heat from the air. This is well shown in Chart IX. (Fig. 9, Plate III.), as well as in Chart IV. (Fig. 4, Plate II.), which may be compared with the chart accompanying the First Report.*

Heating by conduction from the surrounding strata is reduced to a minimum in shafts and roads when the volume of air passing is sufficiently large as shown in the charts just referred to. This is

* *Trans. Inst. M. E.*, 1919-1920, vol. lviii., page 237; Second Report, *ibid.*, page 323.

because the flow of heat through the zone of cooled rock which comes to be formed in course of time round a shaft or airway is comparatively slow. If the air-flow is large, the flow of heat from the strata is insufficient to warm the air more than very slightly; but if the air is flowing very slowly, the heat-flow is sufficient to warm it to practically the temperature of the strata, as shown, for instance, in Chart VIII. (Fig. 8, Plate III.). The practical importance of a large flow of air in controlling underground temperature stands out prominently in the results of the present investigation.

In this country the rate of increase of the natural rock-temperature with depth is always much greater than the increase of air-temperature from compression; and at the collieries hereafter referred to the rate of increase in rock-temperature is 1° Fahr. for about every 60 or 70 feet, as will be shown in a further Report; whereas the air-temperature increase from compression is only 1° Fahr. in 182 feet. In the Witwatersrand district, however, the rock-temperature increase is only about 1° Fahr. in 250 feet, so that if a deep mine were dry, abundant ventilation would warm it, in contrast to the cooling effect in this country.

Heating by oxidation is referred to only incidentally in the present Report, but it is evident that this, also, can be controlled by abundant ventilation.

Increase in the moisture-content of the air is a factor which can usually be controlled as effectively by ventilation, until the actual working-face is reached, as can increase of temperature. This is shown in all the charts except No. VIII. (Fig. 8, Plate III.), which was for a colliery with very wet shaft and roads. But with abundant ventilation, the cooling effect of evaporation from wet roads would evidently keep the temperature along these roads low, and thus indirectly control the amount of moisture in the air and the wet-bulb temperature. The very rapid rise in moisture-content of the air as it passes along a working-face over fresh and relatively moist coal is shown in all the charts.

A study of the data contained in the present Report, in the light of the various physiological and other explanations summarized in the First Report, will, we hope, render much more clear the causes of difficulties ordinarily met with in connexion with the temperature and moisture of the air in deep workings.

OBSERVATIONS OF TEMPERATURE AND MOISTURE IN DEEP COAL-MINES.

By J. P. REES, A.R.S.M.

II.—Methods of Investigation.

The observations of air-temperature and wet-bulb temperature have in all cases been made with a type of whirling hygrometer originally designed for underground work by Mr. J. T. Storrow.

A sketch of this hygrometer—drawn to half scale—is shown in Fig. 12 in the text. Two accurate mercury thermometers, from 6 to 6½ inches long, and with narrow long bulbs, are set in a wooden frame. They are fixed in grooves on cork pads with seccotine, and further secured by two metal bars set flush with the face of the frame. For most of the length of the thermometers the groove is cut right through the wood, so that the thermometers can be read by holding them against the

light. An oval hole is cut in the frame for the bulb of the dry thermometer. A glass reservoir for water is fixed at the bottom of the frame. Above the neck of the reservoir the frame is cut away round the bulb of the wet thermometer. This bulb is kept moist by a slip of muslin, which dips into the reservoir. At the top of the frame two pieces of metal are let into the side, and where they project at the top they are bored to take a spindle. The spindle and its wooden handle are secured by milled nuts, so that by a movement of the wrist a whirling motion can be given to the frame. The frame is carried in a tin case, which has a lid at its top. The lid is secured over the spindle with the handle projecting at the side. The length from the spindle to the centre of the bulbs of the thermometers is about 6 inches. The hygrometer may be easily whirled at 200 revolutions per minute, and the air then passes over the bulbs at the rate of over 600 feet per minute. The prismatic type of thermometer has been found easy to read under all conditions, and from 40° to 110° Fahr. has been found the most useful range for underground work. For surface readings thermometers reading to below freezing-point are, of course, necessary.

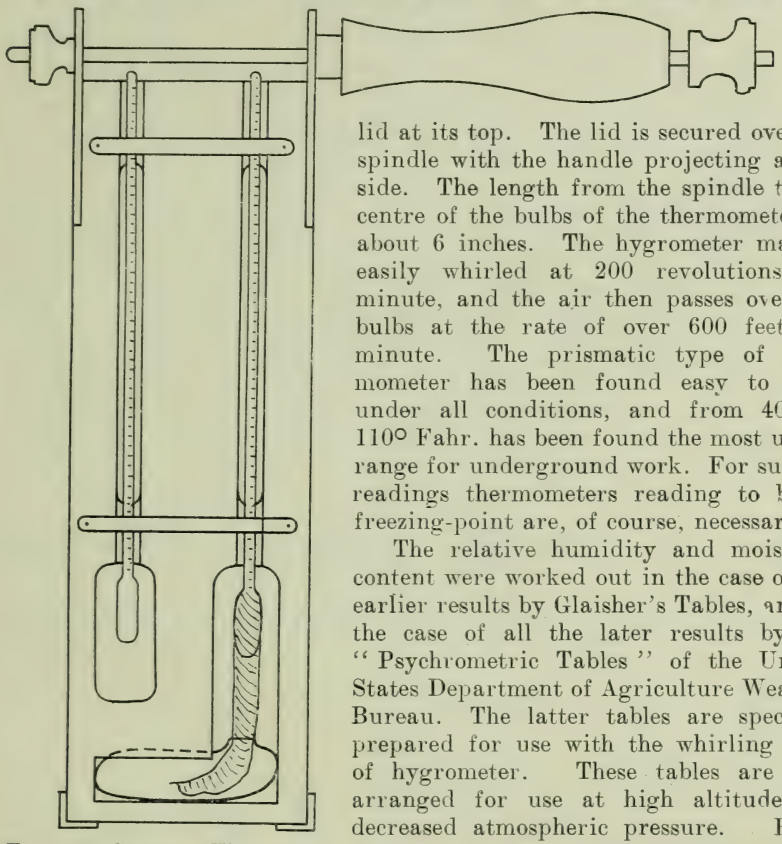


Fig. 12.—Storrow Whirling Hygrometer (Half Size).

The relative humidity and moisture-content were worked out in the case of the earlier results by Glaisher's Tables, and in the case of all the later results by the "Psychrometric Tables" of the United States Department of Agriculture Weather Bureau. The latter tables are specially prepared for use with the whirling type of hygrometer. These tables are also arranged for use at high altitudes or decreased atmospheric pressure. From these a correction to the moisture-content per inch decrease in barometric pressure and per degree Fahrenheit depression of the wet bulb was deduced. The same correction with a contrary sign was then applied to the moisture-content per inch increase in barometric pressure. This correction, however, is so slight as to be almost negligible. From the actual moisture-content the "absolute" moisture-content or grains of moisture in a cubic foot of air at 32° Fahr. and normal pressure has been calculated.*

Observations have been made on five pits in different parts of the country, and in each a series of readings was made from which a graph has been constructed similar to that shown for Bentley Colliery in the First Report.†

* For advantage of this, see First Report, *Trans. Inst. M. E.*, 1919-1920, vol. lviii., page 231.

† *Ibid.*, page 237.

III.—Observations at Pendleton Colliery.

Chart No. I. (Fig. 1, Plate II.) illustrates the average conditions during six different sets of observations from October 28th to November 4th, 1919, in Pendleton Colliery, near Manchester. Tables I. and II. give analyses of the rise in temperature of the dry bulb and wet bulb. To the actual rise in dry-bulb temperature over any section, the calculated loss in temperature due to the cooling effect of evaporation has been added in column 3. Column 4 gives the calculated heating effect of compression per cubic foot of air, and column 5 the result of subtracting the heating effect of compression from the total theoretical rise in temperature. This is the rise due to heat conducted from the walls, and possibly to oxidation. Where the heating effect of oxidation has been determined from analyses of the air, it has been deducted from column 5, and column 7 gives the rise due to conduction alone. The factors influencing the rise in wet bulb are: (*a*) the rise in dry bulb, (*b*) the moisture picked up, and (*c*) any change in volume of the air due to changing temperature and pressure. An inspection of Glaisher's Tables shows that a rise of 10° Fahr. in the temperature of the air causes the wet bulb to rise about 4° Fahr., the amount of moisture in the air being unaltered. This is true over a range from about 35° to about 100° Fahr. The combined effect of compression and rise in temperature on the volume of the air is small, and has been disregarded in the table.

Table I.—Pendleton Colliery. Analysis of Rise in Dry-bulb Temperature of Air.

Column.	1.	2.	3.	4.	5.	6.	7.
Section.	Actual rise.	Loss due to evaporation.	(1)+(2). Total theoretical rise.	Rise due to compression.	(3)-(4). Rise due to conduction and oxidation.	Rise due to oxidation alone.	(5)-(6). Rise or fall due to conduction.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Surface to pit-bottom (1)-(2)	16	8	24	8	16	0	+16
Pit-bottom to split on main brow (2)-(3) ...	19	4	23	9	14	0	+14
Split to 14's level (3)-(4) ...	9	1	10	2	8	0	0
Pit-bottom to end of 14's level (2)-(5)...	36	9	45	11	34	10	+24
14's level (4)-(5) ...	8	4	12	0	12	0	0
Face (5) (10) ..	5	27	32	-2	34	100	-66

Table II.—Pendleton Colliery. Analysis of Rise in Wet-bulb Temperature of Air.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of increased moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1) (2)	12	6	6
Intake (2) (5)	18	14	4
Face (5) (10)	11	2	9

Taking first the dry-bulb curve in Chart No. I., it will be seen from column 7 that the heating effect of the shaft and walls is 16° Fahr.

The mean annual temperature at the surface is, however, higher than that recorded, and the mean annual rise will therefore be less. An observation taken on December 13th, 1919, by Mr. J. Ivon Graham, when the surface-temperature was about 50° Fahr., gives an actual rise of about 11° Fahr. and an increase in moisture-content of 1·09 grains. The heating effect of the shaft and walls will, therefore, be about 11° Fahr. on the average. That the air is heated by the strata to this extent is no doubt due to the small size of the shaft and consequent small volume of air passing down. At the time when the observations were made there was a current of about 40,000 cubic feet of air per minute passing down the shaft.

There is no oxidation as far as the point on the main brow where the air splits to the two districts. Over the remainder of the intake there is a certain amount of oxidation taking place, and a large amount at the face. The work being carried out in connexion with the determination of the geothermic gradient has shown that the natural temperature of the strata at the horizon of the bottom level is about 100° Fahr. The air-temperature at the face end of this level is, therefore, only some 6° Fahr. below the rock-temperature, leaving a very small margin for the rise at the face. Table III. shows the comparison between the rise in dry bulb due to the heating effect of the walls over the sections of the intake before and after the air is split. As soon as the face is reached the temperature rises rapidly until the rock-temperature is reached. Then, no heat being received from the strata, the cooling effects of evaporation of moisture, release of methane, and slight decompression, are sufficient to balance the large heating effect of oxidation of the freshly-won coal. In the first part of the returns there is no cooling effect from evaporation, and with slight compression the temperature rises to its maximum for the circuit, but thereafter falls owing to leakage in of fresh air, to decompression, and to heat returned to the strata.

Table III.—Pendleton Colliery. Comparison of Heating Effect by Conduction per 1,000 Yards over two Sections of the Intake.

Section.	Length.	Heating effect by conduction.	Effect per 1,000 yards.	Average volume of air passing per minute.
	Yards.	Degs. Fahr.	Degs. Fahr.	Cubic feet.
Surface to split on main brow	2,330	21	9	36,000
Split on main brow to face	1,520	22	14·5	12,000

It will be seen from the wet-bulb and moisture-content curves that the intake roads are comparatively dry. At the face the rise in moisture-content is very rapid, due to evaporation of moisture from the freshly-won coal. Owing to the high temperature the air has reached at the face, its capacity for moisture is great. But for this, the increase in moisture-content would have caused a much greater rise in the wet bulb. Thus from Table II. it will be seen that more than three times the amount of moisture evaporated in the shaft is evaporated along the face per cubic foot of air passing; yet the rise in wet bulb at the face is only one-and-a-half times the rise in the shaft.

By comparison of the summer chart (Fig. 2) with the winter chart (Fig. 1) it will be seen that there is no marked rise in the dry-bulb temperature at the face during summer, though perhaps there may be a

rise of 1° Fahr. The temperature of the air at the face is for all practical purposes uninfluenced by the seasonal changes at the surface. There is a perceptible increase in the wet-bulb temperature of about 3° Fahr. The wet-bulb temperature is more sensitive to the seasonal change at the surface (Cf. Committee's Second Report by E. Davies. *Trans. Inst. M. E.*, 1919-1920, Vol. LVIII., page 323.). From the moisture-content curves it will be seen that the air at the surface contains roughly 1½ grains per cubic foot more moisture in the summer. This increase is carried right through the intake to the face. But whereas at the surface temperature an increase of 1½ grains per cubic foot causes a rise in the wet bulb of about 7° Fahr., at the temperature of the air at the face the rise produced is only about 3° Fahr.

IV.—Observations at Pendlebury Colliery.

Chart III. (Fig. 3, Plate II.) illustrates the conditions recorded at Pendlebury Colliery, Lancashire. The factors influencing the rise in temperatures are recorded in Tables IV. and V. The temperature of the air when the readings were taken was 9° or 10° Fahr. lower than the average for the year. From some readings taken by Mr. J. I. Graham when the surface temperature was about 49° Fahr., the heating effect of the strata in the shaft appears to be about 8° Fahr., which will be about the average for the year. About 50,000 cubic feet of air per minute were passing down the shaft. The strata surrounding the main level are wet, and this largely accounts for the amount of moisture evaporated along this section, although observations made by Mr. Graham show that moisture is being picked up in development brows that were being put down from this level and through which a portion of the air circulated. Analysis of the air shows that oxidation of coal is taking place.

Table VI. gives a comparison of the heating effect of conduction and oxidation on the air before and after the ventilating current is split. The fluctuations in the curves at the face are due to fresh air coming in. Owing to continual leakage, the quantity of air reaching the bottom place is small, and the temperature in consequence rises above the natural temperature of the strata. Fresh air comes in at higher levels, and the temperature again falls.

Table IV.—Pendlebury Colliery. Analysis of Rise in Dry-bulb Temperature of Air.

Column.	1.	2.	3.	4.	5.
Section.	Actual rise.	Loss due to evaporation.	(1)+(2).	Rise due to compression.	(3)−(4). Effect of oxidation and conduction.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)-(2)	20·5	6·5	27	10	17
Main brow (3)-(4)	9·0	3·5	12·5	3·5	9·0
Main level (4)-(5)	4·0	8·5	12·5	0	12·5
Low-side brow and slant to face (5)-(6)	6·5	3·0	9·5	1	8·5
Pit-bottom to face (2)-(6)	22	15	37	4·5	32·5
Face (6)-(11) ...	6	17·5	23·5	−1·5	25

TABLE V.—PENDLEBURY COLLIERY. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of increased moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)-(2)	14	8	6
Pit-bottom to foot of main brow (2)-(4)	7	5	2
Main level (4)-(5)	5	2	3
Low-side brow and slant (5)-(6)	4	2	2
Face (6)-(11)	8	2	6
Pit-bottom to face (2)-(6) ...	16	9	7

TABLE VI.—PENDLEBURY COLLIERY. COMPARISON OF HEATING EFFECT OF CONDUCTION AND OXIDATION ON DIFFERENT SECTIONS OF THE INTAKE.

Section.	Length.	Heating effect of conduction and oxidation.	Rise per 1,000 yards.	Volume of air passing per minute.
	Yards.	Degs. Fahr.	Degs. Fahr.	Cubic feet.
Surface to split at end of main level	2,290	32·0	14	18,000
Split at end of main level to face	340	8·5	25	6,000

V.—OBSERVATIONS AT SHELTON DEEP PIT.

Chart IV. (Fig. 4, Plate II.) illustrates the conditions recorded in the Cockshead workings at the Deep Pit of the Shelton Iron, Steel, & Coal Company, North Staffordshire. The district is one that has been newly opened out, and the face is only about 250 yards long. The workings are at great depth. There is very little rise of temperature from conduction in the shaft, down which about 200,000 cubic feet of air were passing per minute; and it will be noticed that between points 2 and 3 of the dry-bulb curve there is a fall in temperature. This is because the observations were made on a fairly warm day in spring, when the surface temperature was well above the average for the time of the year. The rock round the pit-bottom was, therefore, being warmed by the incoming air.

Tables VII. and VIII. analyse the rise in dry-bulb and wet-bulb temperature respectively. Along the bottom level the heating effect of the strata is very great indeed. This is due to a diminished ventilating current, and also to the fact that as the level has been recently opened up the strata were giving off heat rapidly.

Chart V. (Fig. 5, Plate II.) illustrates the conditions found in the same pit, but in workings long developed and about 1,000 feet nearer the surface. By the system on which the coal is worked "jig-brows" are put up at regular intervals from the main level to the face. Air is purposely allowed to leak up each of these, and there is some leakage through the packs, so that though there are about 10,000 cubic feet of air a minute before the first jig-brow, after the last there are only about 2,000 cubic feet a minute passing along the main level. It will be seen from the chart and the analyses (Tables IX. and X.) that it is along the

last part of the level that the rise in dry bulb is most rapid. Nevertheless, the average rate of rise along the main level compares favourably with the average rate of rise in the level of the Cockshead workings, as shown in Chart IV. At the beginning of the face the temperature is only about 4 degrees below the natural rock-temperature. It rises to about that temperature, and thereafter fluctuates according to the amount of fresh air leaking in by the jig-brows. From this chart the advantages and disadvantages of this system of working from the ventilation point of view can be plainly seen. The physiological effects of a good rate of movement of the air are so important that, despite the temperature conditions remaining the same along the face, the cooling power of the ventilation increases rapidly towards the end of the face as the speed of the air passing increases. This point is illustrated by the Kata thermometer results obtained in the Holly Lane working (Table XXII.).

Charts VI. and VII. (Figs. 6 and 7, Plate II. and III.), with Tables XI., XII., XIII., and XIV., illustrate the conditions in the Holly Lane and the Two Yard Seams of the same pit. The method of working is the same, and the charts are very similar in general outline to the last.

TABLE VII.—SHELTON DEEP PIT, COCKSHEAD SEAM. ANALYSIS OF RISE IN DRY BULB TEMPERATURE OF AIR.

Section.	Rise in dry bulb.	Gain in moisture.	Heat of evaporation.	Total rise.	Compression effect.	Conduction. effect.	Rise in temperature per 1,000 yards by conduction.	Ventilation per minute.
	Degs. Fahr.	Grains.	Degs Fahr.	Degs. Fahr.	Degs. Fahr.	Degs Fahr.	Degs. Fahr.	Cubic feet.
Main dip as far as No. 2 landing (3)-(4)	3·4	—	—	3·4	2	1·5	2·5	16,000
Main dip No. 2 landing to bottom (4)-(5) ...	2·3	0·06	0·5	3·0	1	2	9	12,000
Bottom main dip to bottom 45° dip (5)-(6) ...	5·2	0·17	1·5	6·5	2·5	4	14	9,000
Bottom 45° dip to face (6)-(8) ...	11·1	1·71	13·5	24·5	0	24·5	108	7,000

TABLE VIII.—SHELTON DEEP PIT, COCKSHEAD SEAM. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section	Actual rise.	Effect of rise in dry bulb.	Effect of variation in moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Main dip as far as No. 2 landing (3) (4)	1	1·5	−0·5
No. 2 landing to bottom (4) (5)	1·5	1	0·5
45° dip (5) (6)	3	2	1·0
Bottom 45° dip to face (6)-(8)	8	4·5	3·5

TABLE IX.—SHELTON DEEP PIT, RAGMAN SEAM. ANALYSIS OF DRY-BULB TEMPERATURE OF AIR.

Section.	Actual rise in dry bulb.	Gain in moisture-content.	Cooling effect of latent heat of evaporation.	Total rise.	Compression effect.	Conduction effect.	Conduction effect per 1000 yards intake.	Ventilation per minute.
	Degs. Fahr.	Grains.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Cubic Feet.
Shaft (1)–(2) ...	19	1·2	10	29	12	17	—	200,000
Main crut (2)–(5) ..	3	0·13	1	4	—	4	6	50,000
Main dip (5)–(6) ...	5·5	0·3	2·5	8	2·5	5·5	9·5	25,000
Main level (6)–(12)	15·5	3·5	28	43·5	−0·5	44	45	6,000
Face (12)–(20) ...	4·5	1·4	11	15·5	−0·5	16	16	6,000

TABLE X.—SHELTON DEEP PIT, RAGMAN SEAM. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of rise in moisture-content.
	Degs Fahr.	Degs. Fahr.	Degs Fahr.
Shaft (1)–(2)	14·5	7·5	7
Main crut (2)–(5)	1·5	1	0·5
Main dip (5)–(6)	2·5	2	0·5
Main level (6)–(12)	15	6	9
Face (12)–(20)	4·5	2	2·5

TABLE XI.—SHELTON DEEP PIT, HOLLY LANE SEAM, NORTH DISTRICT. ANALYSIS OF RISE IN DRY-BULB TEMPERATURE OF AIR.

Section.	Actual rise in dry bulb.	Gain in moisture content.	Cooling effect of latent heat of evaporation.	Total rise.	Compression effect.	Conduction effect.	Conduction effect per 1,000 yards.	Ventilation per minute.	Length of section.
	Degs. Fahr.	Grains.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Cubic feet.	Yards.
Shaft (1)–(2)	19·2	1·12	9	28	14	14	16·5	200,000	850
Dip (3)–(6) ...	7·9	0·20	1·5	9·5	4·5	5	5	25,000	1,060
Level (6)–(11)	17·5	2·86	23	40·5	0	40·5	53	5,000	760

TABLE XII.—SHELTON DEEP PIT, HOLLY LANE SEAM, NORTH DISTRICT. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section.	Actual.	Effect of rise in dry bulb.	Effect of increase in moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)–(2)	14	8	6
Dip (3)–(6)	3	3	0
Level (6)–(11)	13	7	6

TABLE XIII.—SHELTON DEEP PIT, TWO YARD SEAM. ANALYSIS OF RISE IN DRY-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Gain in moisture-content.	Cooling effect of evaporation.	Total rise.	Compression effect.	Conduction effect.	Conduction effect per 1,000 yards intake.	Ventilation per minute.	Length of section.
	Degs. Fahr.	Grains.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Cubic feet.	Yards.
Shaft (1)–(2)	18·5	1·26	10	28·5	14	14·5	17	200,000	850
Dip (3)–(4)	0·5	0·07	0·5	1	0·5	0·5	3	50,000	170
Level (4)-(10)	19	1·27	10	29	0	29	25	10,000	1160

TABLE XIV.—SHELTON DEEP PIT, TWO YARD SEAM. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of rise in moisture-content.
	Degs Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)–(2)	14	7	7
Dip (3)–(4)	0·5	0	0·5
Level (4)-(10)	11	8	3

VI.—OBSERVATIONS AT BOWHILL COLLIERY.

Chart VIII. (Fig. 8, Plate III.) illustrates the conditions in the deepest workings of Bowhill Colliery, Fifeshire. Tables XV. and XVI. analyse the rise in dry-bulb and wet-bulb temperature throughout the circuit. The shaft is small and rectangular, and in consequence there are only about 40,000 cubic feet of air passing down. At the pit-bottom the air is split to the different workings, so that over the last 1,000 yards of intake before the deepest workings, which have been opened up recently on a small scale, there are only about 6,000 cubic feet of air passing, and just before the fact about 3,000 feet. The intake is very wet, and in consequence of the small ventilation a large amount of moisture is picked up. It will be seen from the chart that the wet-bulb curve keeps close to the dry-bulb curve, until in the returns the air, in spite of fresh air leaking in, is saturated. In the mine this produces a fog of condensing vapour. It will be seen from Table XV. that the cooling effect of the evaporation of moisture is great; nevertheless, at the beginning of the face the temperature of the air is only some 5° Fahr. below the natural rock-temperature as determined by the work already referred to on the determination of the geothermic gradient. At the face the current of air is still further diminished by leakage, and the temperature rises very rapidly to that of the rock-temperature. If the temperature-gradient at this pit were not unusually low, the temperature of the air at the face would be considerably higher and the wet bulb would be inconveniently high. The drop in the moisture-content curve between points 18 and 19 is due to leakage in of fresh air, and gives an indication of the amount of air that is short-circuiting the face.

TABLE XV.—BOWHILL COLLIERY, FIFE. ANALYSIS OF RISE IN DRY-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Gain in moisture-content.	Cooling effect of evaporation.	Total rise.	Compression effect.	Conduction effect.	Conduction effect per 1,000 yards intake.	Ventilation per minute.	Length of section.
	Degs. Fahr.	Grains.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Cubic feet.	Yards.
Shaft (1)-(2)	12·6	2·01	16	28·5	7	21·5	50	40,000	430
Main Dook (3)-(9) ...	6·8	1·02	8	15	3·5	11·5	11·5	20,000	980
Hutts Dook (10)-(14)...	10·4	1·70	13·5	24	4·5	19·5	25	6,000	790
Bottom Level (14)-(15)	2·6	0·79	6·5	9	0	9	39	3,000	230
Face(15)-(18)	6·3	2·34	18·5	25	0	25	210	...	120

TABLE XVI.—BOWHILL COLLIERY, FIFE. ANALYSIS OF RISE IN WET-BULB TEMPERATURE OF AIR.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of rise in moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)-(2)	14·2	5	9
Main Dook (3)-(9)	6·2	3	3
Hutts Dook (10)-(14) ...	8·8	4	5
Bottom Level (14)-(15) ...	2·6	1	1·5
Face (15)-(18)	6·9	2·5	4·5

VII.—OBSERVATIONS AT BENTLEY COLLIERY, YORKSHIRE.

Chart IX. (Fig. 9, Plate III.) shows the conditions during the warmest hours of a summer's day at Bentley Colliery. Tables XVII. and XVIII. give analyses of the rise in dry-bulb and wet-bulb temperatures. It will be seen that despite the heating effect of compression, the effect of the intake is to cool the air until at one point it is actually below the temperature of the air at the surface. At the face it is about 5° Fahr. above the winter temperature (see chart in First Report, *loc. cit.*). With a large volume of air passing, the seasonal changes at the surface have more effect in-bye. In the returns the air rises to the natural rock-temperature. The only rise in the moisture-content is over the last small section of the intake and at the face. The wet-bulb is about 6° Fahr. higher than that recorded in April, 1919 (see First Report). This is mainly due to increased moisture-content at the surface, as in the case recorded at Pendleton. In the returns the wet-bulb rises, owing to the rise in the dry-bulb.

In Tables XIX. and XX. some figures for the rates of rise in the temperature of the air in the shafts and main intakes of different pits are brought together. The circumstances vary so in different pits that no definite conclusions can be reached by comparing them.

Table XXI. gives figures for the ventilating efficiencies met with in two different pits, and shows the extremes that are met with in a well-

ventilated modern pit and in an old pit where the ventilation is a difficult problem.

Table XVII.—Bentley Colliery, South-West District, Right-hand Section. Analysis of Rise in Dry-bulb Temperature of Air.

Section.	Actual rise.	Gain in moisture-content.	Cooling effect of evaporation.	Total rise	Compression.	Conduction effect.	Conduction effect per 1,000 yards.	Ventilation per minute.	Length of section.
	Degs. Fahr.	Grains.	Degs. Fahr.	Degs Fahr.	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.	Cubic feet.	Yards.
Intake road (2)–(10) ...	3·5	0·39	3	6·5	0	6·5	3	28,000	2,310
Face (10)-(13)...	3	1·22	9·5	12·5	0	12·5	35	20,000	360
Return (13)-(19)	3	0·02	—	3	0	3	1·5	26,000	2,520

Table XVIII.—Bentley Colliery, South-West District, Right-hand Section. Analysis of Rise in Wet-bulb Temperature of Air.

Section.	Actual rise.	Effect of rise in dry bulb.	Effect of rise in moisture-content.
	Degs. Fahr.	Degs. Fahr.	Degs. Fahr.
Shaft (1)–(2)	1	1	—
Intake road (2)–(10)	2·5	1·5	1
Face (10)–(13)	4·5	1	3·5
Return (13)–(19)	1	1	—

Table XXII. gives the results of some observations with Prof. Hill's "Kata" thermometer. Owing to the gross inaccuracy of anemometer readings at low speeds, the figures for the speeds of air at Pendleton cannot be relied upon within 100 per cent. error. The speeds calculated from the Kata readings are accurate to about 12 per cent. error. In Pendleton the air was above blood-temperature, and the cooling depends on the wet-bulb temperature and the speed of the air alone. A comparison of the two readings taken there illustrates the unimportance of the temperature of the air (dry-bulb) as a factor in keeping the body cool. The reading in the Holly Lane Seam, in-bye of 11's Jig, was taken when for the time being the air was only just moving. Under these conditions the cooling power on the body of the atmosphere is only the same as in the top place of the face at Pendleton, where the temperature conditions were very severe, but where a fair current of air was moving. This result illustrates very forcibly the vital necessary from a physiological point of view of having a good current of air moving in any place where the wet-bulb temperature approaches 80° Fahr.

On the other hand, where, as in-bye of 13's Jig, No. 1 District, Two Yard Seam, the wet-bulb is down to about 70° Fahr., the speed of the air though important ceases to be so vital. The result obtained in Bentley Colliery gives an idea of the cooling conditions prevailing in a well-ventilated pit.

Chart X (Fig. 10, Plate III.) is a curve showing the relation of the wet-bulb temperatures to the dry-bulb temperatures throughout the year on the surface. From the records of the Radcliffe Observatory, Oxford,

the mean monthly values of the dry-bulb over a period of five years have been taken and the corresponding values of the wet-bulb plotted against them. It will be seen that the wet-bulb does not rise as fast as does the dry-bulb. As it has been shown that the rise in wet-bulb on the surface has an appreciable effect underground, this is a fortunate occurrence. Doubtless tropical countries might not show to the same advantage. Chart XI. (Fig. 11, Plate III.) shows the relation of the moisture-content to the dry-bulb temperature throughout the year, the records being obtained from the same observatory. The mean monthly values in this case were averaged for the five years before being plotted.

TABLE XIX.—COMPARISON OF RISE IN DRY-BULB TEMPERATURE OF AIR IN SHAFTS OF DIFFERENT PITS.

Pit.	Depth.	Ventilation per minute.	Surface temperature.	Pit-bottom.	Rise.	Moisture picked up, in grains per cubic feet, at N.T.P.	Total.	Heating effect of compression.	Heating effect of conduction.	Diameter of shaft.	Heating effect of conduction per 1,000 feet depth.
	Feet.	Cubic Feet.	Degs Fahr.	Degs. Fahr.	Degs. Fahr.	Grains	Degs. Fahr	Degs. Fahr.	Degs. Fahr.	Feet.	Degs. Fahr.
Bentley* ...	1,875	250,000	51·3	59·4	8·1	0·27	10·1	10·5	Nil.	20	0
Pendleton ...	1,530	40,000	50	61	11	1·1	20	8·5	11·5	8	7·5
Pendlebury	1,770	50,000	49	62	13	0·65	18	10	8	10	7·5
Shelton ...	2,560	200,000	48	65	17	1·15	26	14	12	17	4·5
Bowhill ...	1,330	40,000	47	57·5	10·5	2·67	32	7·5	24·5	27 × 11	18·5

TABLE XX.—SHOWING THE HEATING EFFECT OF THE STRATA IN THE MAIN INTAKES OF DIFFERENT PITS.

Pit.	Temperature at end of main intake.	Rise from surface.	Ratio of rise to increase in strata temperature.	Depth.	Compression effect.	Conduction effect.	Length from surface.	Conduction effect per 1,000 yards.
	Degs. Fahr.	Degs. Fahr.	Per cent	Feet.	Degs. Fahr.	Degs. Fahr.	Yards.	Degs. Fahr.
Bentley*	62 5	14·5	50	1,875	10·5	4	2,700	1·5
Pendleton ...	76·5	26·5	59	3,170	17·5	9	2,330	4
Pendlebury ...	72·5	22·5	58	2,420	13·5	9·0	1,460	6
Shelton, Ragman	68 0	20·0	46	2,660	14·5	5·5	1,990	3
Shelton, Cockshead	77·0	29·0	48	3,560	19·5	9·5	2,060	4·5
Bowhill	76·5	28·5	81	2,780	15·5	13	2,570	5

TABLE XXI.—EFFICIENCY OF VENTILATION.

Pit.	A. Amount of air entering district per minute.	B. Amount of air leaving face per minute.	Efficiency on ratio B : A.
	Cubic feet.	Cubic feet.	Per cent.
Bentley	27,000	20,000	74
Pendleton	12,000	4,500	38

* Taken from First Report.

TABLE XXII.—TABULATED RESULTS OF READINGS TAKEN WITH THE "KATA" THERMOMETER AT PENDLETON PIT, SHELTON DEEP PIT, AND BENTLEY PIT.

Position.	Temperature.		Speed of air.	Total cooling power. ϕ
	Dry.	Wet.		
PENDLETON.—	Degs. Fahr.	Degs. Fahr.	Ft. per min.	
Face : Top place	99·7	85·2	110*a*	9
Face : Airway to Martletons place	101·5	80·4	120*a*	17
SHELTON DEEP PIT.—				
Ragman Seam, South District.				
Face { North of No. 1 Jig ...	88·3	78·3	60*b*	13
Face { North of No. 10 Jig ...	87·0	76·0	60*b*	15
Holly Lane Seam, North District.				
Face { In-bye 11's Jig	90·7	78·0	5*b*	9
Face { In-bye 4's Jig	91·2	77·2	60*b*	17
Two Yard Seam, No. 1 District.				
Face { South end	84·2	73·0	190*b*	24
Face { In-bye 13's Jig	85·1	69·9	10*b*	16
BENTLEY.—				
S.W. District, right-hand side ..	—	—	175*a*	—
Face	70·0	60·6	230*b*	32

a Readings taken with anemometer.
b Figures calculated from dry-bulb "Kata" readings. Error about 12 per cent.
ϕ Total cooling power in millicalories per square centimetre per second of surface exposed.

In conclusion, I have to thank all those colliery officials without whose help this work could not have been done. I am especially indebted to Dr. Haldane and to Mr. J. Ivon Graham for guidance and help in every way.

Dr. J. S. HALDANE (Oxford): The work of this Committee is, of course, the work of many people, and the Report would have been quite impossible but for the work done in the pits by several members of the Committee who were on the spot to direct matters.

I do not think that I have anything to add to the paper beyond this: there is a very great deal to be learnt by studying the charts and comparing them with what is happening in other pits. You will see the details of how the different causes have led to troubles in regard to the temperature underground—whether the high temperature is due, say, to a slow air-current, or to heating by compression, or to heating by oxidation, or whatever it may be. You can see it all there quite plainly. These charts deal with the conditions, and I think that in some cases they show the limit under which a man can work economically in a coal-mine. Some of these places are very hot. In the Lancashire pit, for instance, it is the custom for the men to work stark naked, with literally nothing on but their boots. Of course in hotter places, such as in some gold-mines and Cornish tin-mines, the conditions as regards heat are worse. I should say, judging from reading the accounts in a recent paper by Mr. Clifford, that in the Transvaal they do

FIG. ...ICAL DEPTH ...M SURFACE FEET.

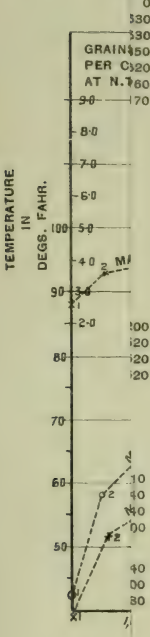


FIG. 3.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, PENDLEBURY COLLIERY, NOVEMBER, 1919.

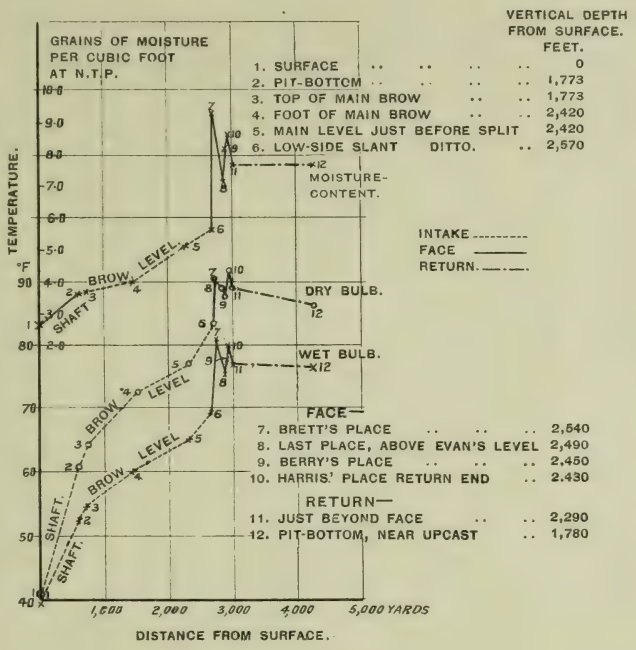


FIG. ...VERTICAL ...PTH FROM ...SURFACE. FEET.

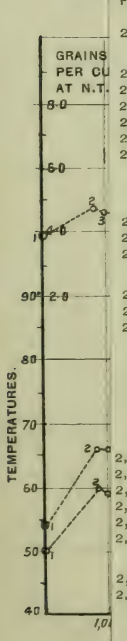


FIG. 6.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, SHELTON DEEP PIT, HOLLY LANE SEAM. NORTH DISTRICT, MARCH. 1920.

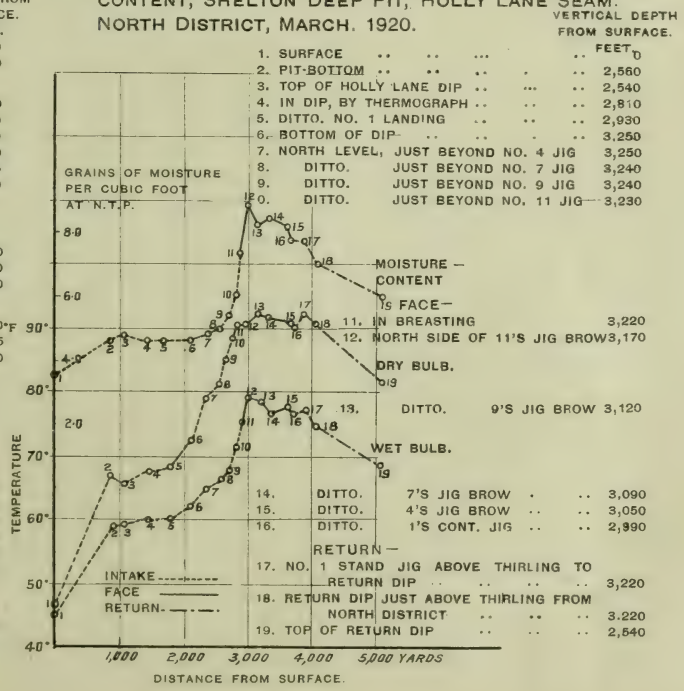


FIG. 1.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, PENDLETON COLLIERY, NOVEMBER, 1919.

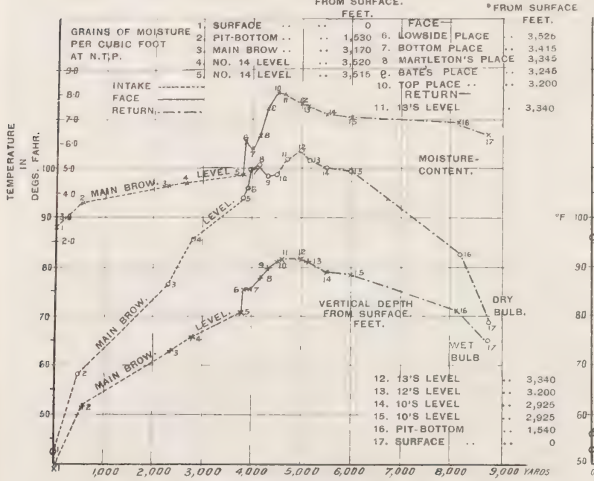


FIG. 2.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, PENDLETON COLLIERY, JULY, 1920.

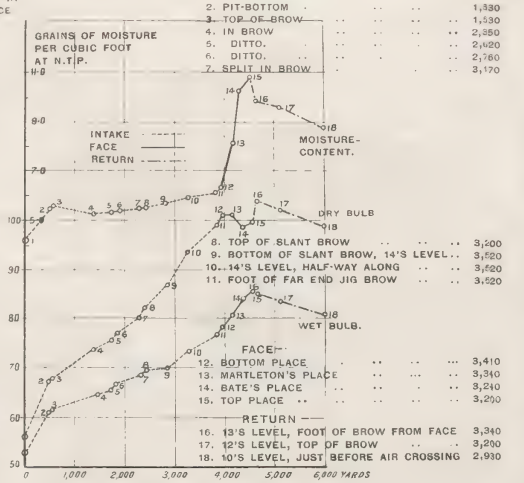


FIG. 3.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, PENDLEBURY COLLIERY, NOVEMBER, 1919.

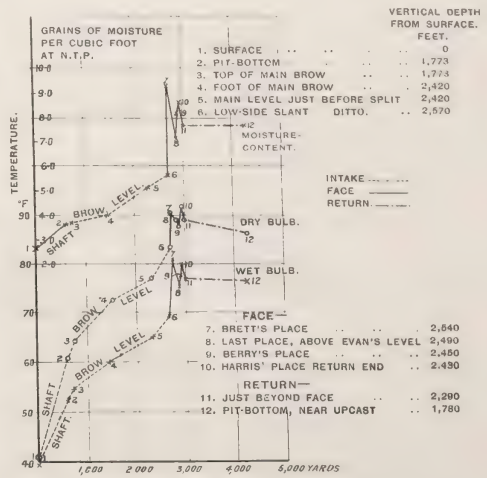


FIG. 4.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, SHELTON DEEP PIT, COCKSHEAD SEAM 45° DISTRICT, MARCH, 1920.

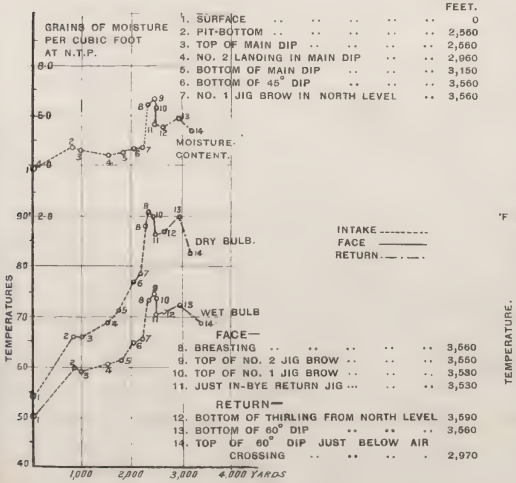


FIG. 5.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, SHELTON DEEP PIT, RAGMAN SEAM, FEBRUARY, 1920.

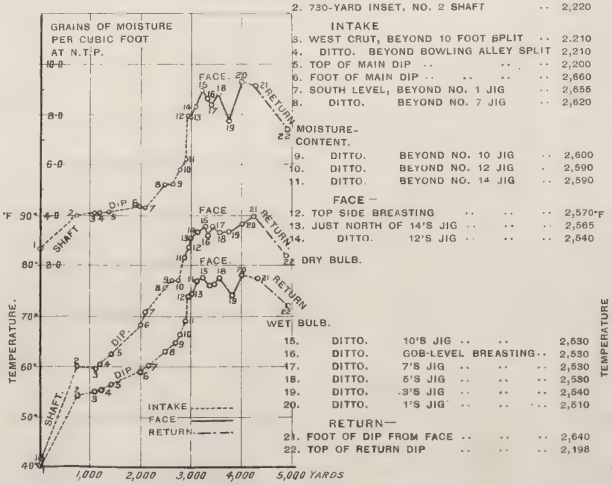
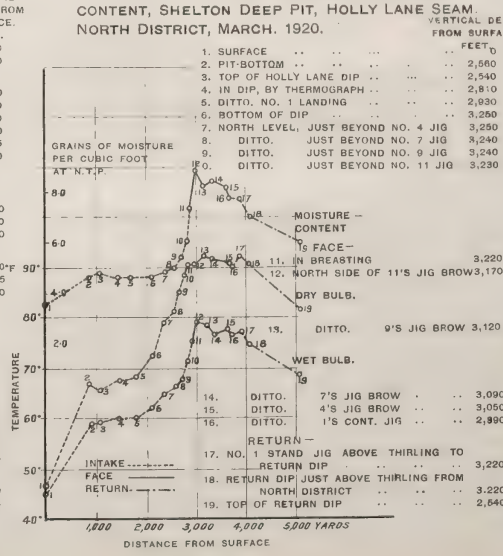
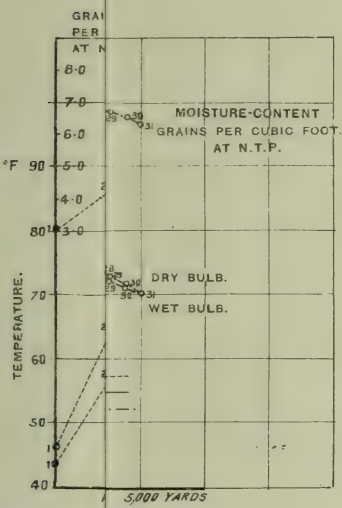


FIG. 6.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, SHELTON DEEP PIT, HOLLY LANE SEAM, NORTH DISTRICT, MARCH. 1920.



And.ᵛ Reid & Comp.ᵛ L.ᵗᵈ Newcastle upon Tyne

FIG. 7.—CES AND MOISTURE-CONTE...IERY, FIFE, MARCH



...CE.

		VERTICAL DEPTH BELOW SURFACE. FEET.
1.	SURFACE	0
2.	PIT-BOTTOM, DOWNCAST	1,278
3.	TOP OF MAIN DOOK	1,270
4.	IN MAIN DOOK	1,440
5.	DITTO.	1,590
6.	DITTO.	1,730
7.	DITTO.	1,810
8	DITTO.	1,860
9.	BOTTOM MAIN DOOK	1,930
10.	TOP OF HUTT'S DOOK	1,930
11.	IN HUTT'S DOOK	2,180
12.	DITTO.	2,390
13.	DITTO.	2,580
14.	BOTTOM OF HUTT'S DOOK	2,790
15.	NO. 15 LEVEL, JUNCTION WITH SLOPE DOOK	2,780
	FACE—	
16.	PRATT'S LEVEL	2,790
17.	END OF NO. 15 LEVEL	2,780
18.	WHITE'S LEVEL	2,770
	RETURN—	
19.	AT JUNCTION WITH SLOPE DOOK	2,770
20.	TOP OF SLOPE DOOK	2,500
21.	TOP OF HUTT'S RETURN DOOK	2 240
22.	IN SPENCE'S DOOK	2,230
23.	DITTO.	2,100
24.	DITTO.	2,020
25.	TOP OF SPENCE'S DOOK	1,930
26.	BOTTOM OF BOGIE DOOK	1,930
27.	IN BOGIE DOOK	1,860
28.	DITTO.	1,730
29.	DITTO.	1,670
30.	DITTO.	1,420
31.	TOP OF BOGIE DOOK	1,270

FIG. 9.— BULB TO CON... RECORDS TRIC... AND ARE ...VE YEARS

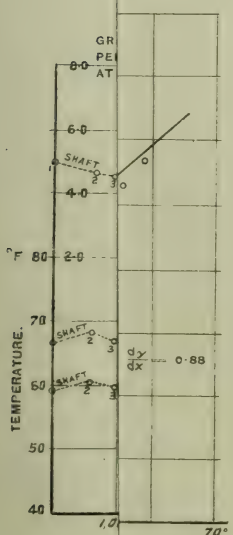


FIG. 11.—CURVE SHOWING RELATION OF MOISTURE IN A CUBIC FOOT OF AIR TO DRY-BULB TEMPERATURE. FIGURES OBTAINED FROM RECORDS OF RADCLIFFE OBSERVATORY, OXFORD, AND ARE MEAN MONTHLY VALUES FOR THE FIVE YEARS 1906 TO 1910 INCLUSIVE.

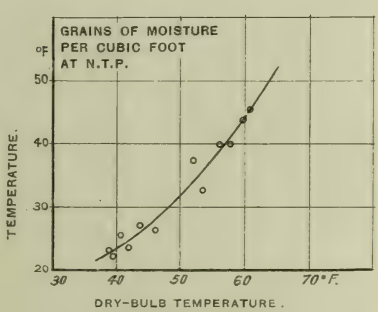
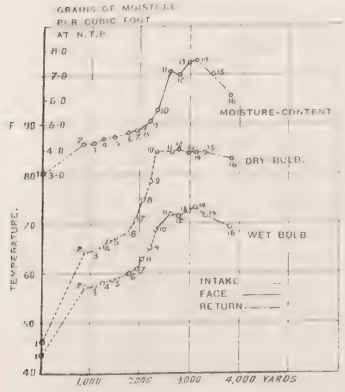
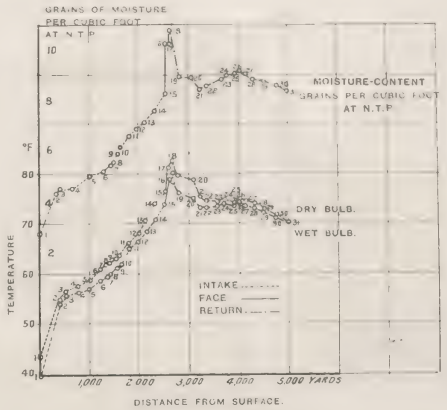


FIG. 7.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, SHELTON DEEP PIT, TWO YARD SEAM, MARCH, 1920.



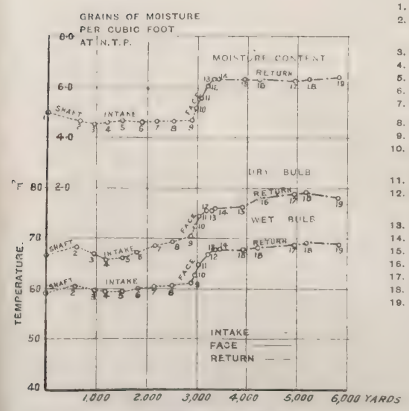
		DISTANCE FROM SURFACE. YARDS.	VERTICAL DEPTH FROM SURFACE. FEET.
1	SURFACE	0	0
2	PIT-BOTTOM, BY THERMOGRAPH	650	2,560
	INTAKE—		
3	TOP OF MAIN DIP	1,040	2,540
4	BOTTOM OF DIP	1,210	2,635
5	IN LEVEL, BY PREPARATORY STOPPING	1,450	2,630
6	JUST IN-BYE 6'S STAND JIG	1,740	2,630
7	DITTO. 8'S STAND JIG	1,940	2,620
8	DITTO. 10'S STAND JIG	2,060	2,620
9	DITTO. 18'S STAND JIG	2,240	2,600
	FACE—		
10.	NORTH SIDE OF 14'S JIG	2,370	2,530
11.	DITTO. 10'S JIG	2,620	2,560
12.	DITTO. 8'S JIG	2,730	2,490
13.	DITTO. 6'S JIG	2,950	2,600
14.	DITTO. RETURN BROW	2,520	2,520
	RETURN—		
15.	BY PREPARATORY STOPPING	3,320	2,560
16.	TOP OF RETURN DIP	3,790	2,540

FIG. 8.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, BOWHILL COLLIERY, FIFE, APRIL, 1919.



		VERTICAL DEPTH BELOW SURFACE FEET
1.	SURFACE	0
2.	PIT-BOTTOM, DOWNCAST	1,278
3.	TOP OF MAIN DOOK	1,270
4.	IN MAIN DOOK	1,440
5.	DITTO.	1,590
6.	DITTO.	1,730
7.	DITTO.	1,810
8.	DITTO	1,860
9.	BOTTOM MAIN DOOK	1,930
10.	TOP OF HUTT'S DOOK	1,930
11.	IN HUTT'S DOOK	2,180
12.	DITTO.	2,390
13.	DITTO.	2,660
14.	BOTTOM OF HUTT'S DOOK	2,790
15.	NO. 15 LEVEL, JUNCTION WITH SLOPE DOOK	2,780
	FACE—	
16.	PRATT'S LEVEL	2,790
17.	END OF NO. 15 LEVEL	2,780
18.	WHITE'S LEVEL	2,770
	RETURN—	
19.	AT JUNCTION WITH SLOPE DOOK	2,770
20.	TOP OF SLOPE DOOK	2,500
21.	TOP OF HUTT'S RETURN DOOK	2,240
22.	IN SPENCE'S DOOK	2,230
23.	DITTO.	2,100
24.	DITTO.	2,020
25.	TOP OF SPENCE'S DOOK	1,980
26.	BOTTOM OF BOGIE DOOK	1,980
27.	IN BOGIE DOOK	1,860
28.	DITTO.	1,780
29.	DITTO.	1,670
30.	DITTO.	1,420
31.	TOP OF BOGIE DOOK	1,270

FIG. 9.—CHART OF TEMPERATURES AND MOISTURE-CONTENT, BENTLEY COLLIERY, SOUTH-WEST DISTRICT, RIGHT-HAND SECTION, JULY 19, 1920.



1. SURFACE.
2. PIT-BOTTOM.

INTAKE—

3. NO. 12 MANHOLE.
4. 1ST SLIT.
5. 3RD SLIT.
6. 5TH SLIT.
7. 7TH SLIT.
8. 9TH SLIT.
9. 11TH SLIT.
10. 50 YARDS FROM FACE.

FACE—

11. BY TRAVELLING-ROAD GATE.
12. BY SECOND WORKING CROSS-GATE.

RETURN—

13. 50 YARDS FROM FACE.
14. BEYOND FIRST WORKING CROSS-GATE.
15. BY 1ST SPLIT.
16. AT CROSS ROADS.
17. BEYOND LAST SLIT TO TRAVELLING-ROAD.
18. BEYOND JUNCTION OF RETURN SPLITS.
19. MOUTHING, NO. 2 SHAFT.

DEPTH OF SHAFT, 625 YARDS.

INTAKE, FACE, AND RETURN AT APPROXIMATELY SAME LEVEL.

FIG. 10.—CURVE SHOWING RELATION OF WET BULB TO DRY BULB. FIGURES OBTAINED FROM RECORDS OF RADCLIFFE OBSERVATORY, OXFORD, AND ARE MEAN MONTHLY VALUES FOR THE FIVE YEARS 1906 TO 1910 INCLUSIVE.

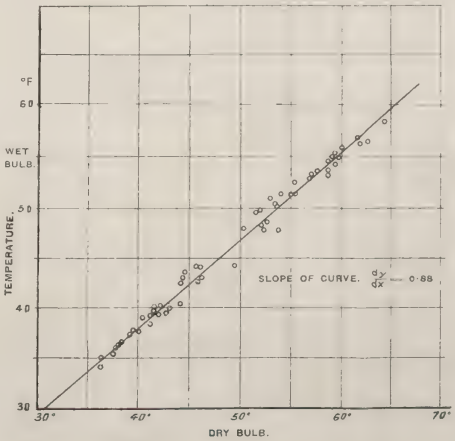
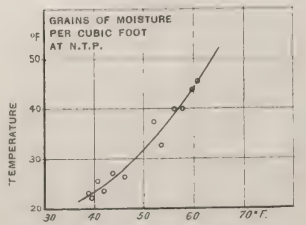


FIG. 11.—CURVE SHOWING RELATION OF MOISTURE IN A CUBIC FOOT OF AIR TO DRY-BULB TEMPERATURE. FIGURES OBTAINED FROM RECORDS OF RADCLIFFE OBSERVATORY, OXFORD, AND ARE MEAN MONTHLY VALUES FOR THE FIVE YEARS 1906 TO 1910 INCLUSIVE.



And.ᵂ Reid & Compᵞ Lᵗᵈ Newcastle upon Tyne

not know what working in a hot place is, because they are so well protected against heat by the very slow rate at which the temperature rises with increase of depth. To see really hot places you must go to some of the mines in Cornwall, or to the Morro Velho Mine in Brazil, where the conditions also are extreme. If you analyse a chart like those accompanying Mr. Rees' paper, you can ascertain what is causing the trouble, and how to get rid of it, whether by lowering the moisture in the air, as they are doing with such great success apparently at Morro Velho, or by improving the ventilation, which is generally the easiest way in this country, but may be quite impossible in some cases where there is a small shaft and sufficient capital cannot be obtained to sink the shaft which is really required to work at that depth. Something might be done by the use of underground fans, and I think that a system of cold-water pipes for cooling might be introduced and cold water pumped and circulated round the workings. That, I hope, will be tried some time or other. Hot-water pipes are used with great success above ground, and I do not see why we should not use cold-water pipes underground on the same principle.

Prof. Henry Louis (Newcastle-upon-Tyne): We are immensely indebted to this Committee for the large amount of work that it has done, and for the valuable information that has been collected, which I am at present trying to understand. If you look, for instance, at the first chart (Fig. 1) there is a statement there that No. 17 is an observation station at the surface, and yet in the line of abscissæ it is marked off at something like 8,700 yards from the surface. It is quite obvious that those two statements cannot be correct. Perhaps Mr. Rees will tell me whether "distance from surface" at the bottom of the chart is not meant to be "distance from the collar of the downcast shaft."

Mr. J. P. Rees: That is so.

Prof. Henry Louis: I want to ask Dr. Haldane whether he is really prepared to maintain his statement that heating by compression cannot be obviated except at the expense of evaporation. Can any amount of evaporation obviate heat by compression? It may mask it.

Dr. Haldane: Yes, it is only masked.

Prof. Henry Louis: Obviously no amount of evaporation can alter the fact, but it may mask the effect.

Would some physicist be good enough to explain exactly how the heat by compression enters into the problem. I assume that we are dealing with mines that are ventilated in the usual way by a suction fan. If that is the case, the air at the mouth of the downcast pit will be at atmospheric pressure. The air travels through the mine, and the pressure will decrease continuously till it reaches the fan. There is never any increase of pressure; the pressure decreases all the time. If water-gauges could be taken all along the mine from the mouth of the downcast to the fan, a constant decrease of pressure all the way from the collar of the downcast to the fan would be observed. Where, then, does the compression come in? There is a constant expansion of air, and no compression anywhere as far as I can make out. Will someone, therefore, explain how in the case of continued expansion there can be compression producing heat?

Dr. Haldane: The barometric pressure at the top of the shaft is, say, 30 inches; at the bottom it will be, say, 32 inches if the shaft is about 2,000 feet deep. That air is compressed.

Prof. Henry Louis : It would be compressed if it were not in motion, but it is moving the whole time.

Dr. Haldane : The barometer is a pressure-gauge, and it shows 30 inches at the top and 32 inches at the bottom.

Prof. Henry Louis : The water-gauge shows 0 at the top and 0·1 at the bottom.

Dr. Haldane : But that is only a differential gauge. The other is a gauge showing the actual pressure. An extra 2 inches of mercury is about 30 inches of water pressure.

Prof. Henry Louis : If the water-gauge shows expansion, have you corrected for the expansion of the air in travelling through the mine? I am not in the least arguing that my point of view is right; I simply want the point explained. It has puzzled me, and I want to know whether that expansion of air throughout the mine has been taken into account.

Dr. Haldane : The expansion would tend to cool the air as it passes through, but it is so small. Two inches or so of water-gauge is nothing compared with the 30 inches which you get as the air passes down the shaft.

Prof. Henry Louis : But has it been taken into account? Suppose you have 10 inches of water-gauge, has that been taken into account in these calculations?

Dr. Haldane : There never was anything like that at the pit-bottom in any of these pits.

Mr. J. P. Rees : The pressure is read with an aneroid barometer, which records the pressure on the surface plus the increase due to the increase in depth minus the decrease in pressure due to the exhaust ventilation, so that it is taken into account.

Prof. Henry Louis : That answers my question completely.

Sir John Cadman, K.C.M.G. (London): May I remind the meeting of the origin of this Committee, which was in the first place appointed by The Institution of Mining Engineers and then taken over by the Department of Scientific and Industrial Research. A great deal of work has been done, and it is a very tedious task to collect the amount of data that has been tabulated in this Report. It entails an enormous amount of very hard work, spread over a long period of time. It takes quite a long time even to interpret the records that have been obtained, and great credit is due to Mr. Rees and those who have collaborated with him.

One of the conclusions is worthy of special note. In order to control the temperatures in deep mines, large volumes of air are necessary. For large volumes of air large shafts and large sectional areas of roadways are required, and large expenditure of capital is necessary. At the present time it is all important to realize that if mining in the future is to be conducted efficiently, those who are going to carry on the industry must be prepared to spend far more capital than has hitherto been necessary.

I do not want to take up the discussion on certain sections of the paper—that we have to do in the Committee; but I should like to repeat my tribute to the workers, and also to Dr. Haldane for the very keen attention that has been given to this most important subject.

Mr. R. W. Dron (Glasgow): It is stated in the introduction to the paper that—

"Heating by compression cannot be oviated, except at the expense of evaporation; but it can be, and to a large extent always is, averaged over the year in the actual workings of a mine, the walls of the shaft and roads giving off more or less heat to the air according as the external temperature is lower or higher."

I cannot see why the heating by compression is averaged over the year by the conductivity of the walls at the side of the shaft. As the statement stands, I am rather puzzled to know what it means. The previous sentence is: "The heat and moisture given off from men, horses, and lamps is scarcely appreciable in a coal-mine." Practically, that is quite correct, speaking of the general ventilation of a coal-mine; but in the practical working of a mine the men are not always in the general ventilation. I happened to be engaged upon litigation a few years ago in connexion with a mine in Scotland in which a man was of necessity working in a place which was situated a little distance off the main air-current. The temperature in the working-place was raised by the presence of men and lamps. The mine was well ventilated, and the air-current was cool, but the man, coming out from the warm place into the main air-current, stated that he had contracted pneumonia, and sued the company for damages. The presence of men and lamps may make a difference in the actual working-places of the mine, and I think the Committee should keep that point in view, although with regard to the general effect it is perfectly correct to say that it does not affect the ventilation generally.

Prof. F. E. Armstrong (Sheffield University) wrote: Perhaps the statement in the introduction to the paper, to the effect that where a low geothermic gradient prevails and the mine is dry abundant ventilation will warm it, may prove misleading. Although the effect of compression in raising the actual temperature of the air may bring it to a higher temperature than that of the rocks, it is evident that the cooling effect on the human body will be increased by abundant ventilation despite the temperature, and that abundant ventilation is desirable in such mines from the point of view of its effect in keeping down the body-temperature of the workers.

The figure given in Table I. of the calculated increase in temperature of 100° Fahr. at the face, due to oxidation alone, is very striking, and in view of the very small excess of the air-temperature over that of the rocks, and that in only part of the face, the calculated decrease due to conduction alone is equally striking. Do these figures represent the considered opinion of the Committee? No similar figures, separating the effects of oxidation and conduction, are given for the other collieries, and it would be very interesting if such figures could be given for comparison, together with the observations upon which the figures for oxidation effect are based. Further, if we are to assume that the oxidation effect is very much smaller at the other collieries, it would be interesting to have the Committee's opinion of the reasons for the difference.

Mr. J. P. Rees (Birmingham University): Prof. F. E. Armstrong in his written communication asks for information as to the figures given in Table I. for the calculated increase in temperature due to oxidation. The samples of the air were taken by Mr. J. Ivon Graham and myself.

The following are the results of analyses made by Mr. J. Ivon Graham :—

(1) Sample taken just before the face at Pendleton.

	Per cent.
Carbon dioxide	0·0925
Methane	0·05
Oxygen	20·83
Nitrogen	79·02

(2) Sample taken just beyond the end of the face at Pendleton.

	Per cent.
Carbon dioxide	0·20
Methane	1·02
Oxygen	19·98
Nitrogen	78·80

From these figures the actual loss of oxygen per cubic foot of air can be calculated. In his experiments at the Doncaster Coal Owners' Laboratory, Mr. T. F. Winmill (*Trans. Inst. M. E.*, 1914-1915, Vol. XLVIII., page 510) found that for every cubic centimetre of oxygen absorbed by fresh coal, 2·1 calories were produced—a heating effect therefore, of 59,430 calories per cubic foot of oxygen absorbed. The calculation of the rise in temperature that would take place is based on this figure.

In Table I. it is assumed that this heat is taken up by the surrounding rock. Actually there is no doubt that the release of methane has a large cooling effect. No figures are as yet available to estimate this effect.

As regards the heating effect of oxidation at the face in other pits, pressure of work has up to the present prevented figures from being obtained, although doubtless they would in most cases be equally striking, and show that there was nothing exceptional about the Pendleton figures.

CHARACTERISTICS OF OUTBURSTS OF GAS IN MINES.

By Prof. HENRY BRIGGS, D.Sc., Ph.D., A.R.S.M.

I.—Introduction.

Sudden outbursts of firedamp, although not frequent in this country, have occurred often enough to make their study a matter of considerable practical importance; and one variety of outburst, namely, that from the solid coal, possesses features of great scientific interest. This paper attempts a review of the circumstances attending these irruptions, and sets forth the results of experiments bearing on the cause of the recent Ponthenry outbursts (1).*

As is generally known, the highly-contorted seams of the Mons Basin have been for many years especially liable to sudden outbursts of firedamp, which invariably come from the solid coal, and have occasionally been of great magnitude. During the thirty years from 1869 to 1898, comprising 9,000 working days, there were in Belgium no less than 237 of these occurrences. In Great Britain firedamp has been the sole gas emitted by these outbursts; but in the Gard district of France and in the area lying between Waldenberg and Neurode, Lower Silesia, there have been numerous irruptions of "carbon dioxide."† The largest outburst which has occurred in any mine was one of carbon dioxide; it took place in July, 1907, at the Nord d'Alais Colliery, Gard, during the preliminary operations of opening-out in a thick seam (2). On this occasion a number of shots were fired electrically from the surface; they were followed by the ejection from the shafts of an enormous quantity of black dust, which accumulated to a depth of 10 feet round the shaft-mouths. About 1,000 tons of coal-dust were blown out, and spread over 50 or 60 acres at the surface. The shafts and roads adjacent to them were choked with fine coal and dust, of which altogether 4,000 tons were subsequently removed. The carbon dioxide poured over the surface; there were cases of asphyxiation and partial asphyxiation, and dogs and birds were killed.

Mr. James Ashworth (3) has described a firedamp outburst which, having regard to the amount of coal projected from the face, was of a magnitude but little inferior to the last instance. It took place in November, 1904, at the Morrissey Colliery, British Columbia, caused fourteen deaths, and led to the closing of the mine. There had been two large bursts the previous year; on this occasion the irruption, which was from a seam of soft non-bituminous coal, displaced 3,500 tons, and the efflux of gas was estimated by Mr. Ashworth at from 2,000,000 to 3,000,000 cubic feet.

Another large-scale firedamp irruption occurred in 1879 at the Agrappe Colliery, Belgium—a mine notorious for sudden outbursts—when over 12,000,000 cubic feet of gas were discharged and 121 lives were lost (4) (5). The gas became ignited at the shaft-mouths, and burned for many

* The numbers in brackets refer to the bibliography appended to the paper.

† The exact composition of the gas is not known to the writer.

hours with a flame 150 feet high. The seam lay at a depth of 2,000 feet. The blast blew 420 tons of fine coal and dust into the heading in which the irruption took place.

In a number of outbursts which occurred at the Bessèges Mines prior to 1892, the firedamp was accompanied by sulphuretted hydrogen—a very unusual feature (6).

A great outrush took place in Saxony in 1875 at a depth of 1,659 feet while sinking through Permian strata; the gas on that occasion was blackdamp (nitrogen plus carbon dioxide) mixed with a small proportion of firedamp.

II.—Outbursts from the Roof and Floor.

With the exception of the last-mentioned instance, those so far given are all of the variety in which the gas bursts out from the coal itself. There is another kind of irruption of an entirely different character, where large volumes of firedamp are suddenly flung into the workings from the floor or roof. A typical example was the outburst that occurred at the Strafford Main Colliery, Barnsley, in 1867 (7), where the Silkstone Seam, 6 feet thick, was being worked at a depth of 720 feet. The floor began lifting towards one end of a longwall face 300 yards in length, and suddenly, after a very heavy "weighting," wide cracks, parallel to the face, opened in the floor, and gas rushed out. About 150,000 cubic feet of firedamp appear to have been emitted in seven minutes, and gas continued to be discharged, at a gradually lessening rate, for six weeks. There were similar outbursts in the same pit in 1870 and 1877 (8). The stratum immediately under the seam, and for 22 feet below it, was of very hard stone. Under that the strata were softer. A bore set down in the floor did not meet gas until it had reached a depth of 35 feet; after that depth several gassy beds were encountered. Mr. W. H. Chambers described (8) a series of five outbursts in the same seam at the Thorncliffe Colliery; in each case the blasts were accompanied by a heavy weighting, and the floor was thrust up at, and parallel to, a longwall face for a distance of 60 yards. Messrs. J. Willen and R. Miller (8) also related how, in 1876, at the New Oaks Colliery a great outrush of gas occurred from a large fracture in the floor, the latter being thrust up until a height of 6 feet was reduced to a mere creeping road, and the seatstone (a hard thill) was thrown up on end in long, massive lumps. There was still another of these irruptions from the floor in 1889 between a nip-out and a fault in the Haigh Moor Seam, Whitwood Colliery (9), and at a depth of 885 feet; the gas apparently came from a thin seam below.

There are many cases on record where gas in large volume has blown out in similar fashion from the roof, usually after an exceptionally heavy "weighting." There was an occurrence of this description at the Houghton Main Colliery in 1889 (10). A similar one, which filled with firedamp a considerable part of the workings of the Coxlodge Colliery, took place in 1868; it was due to a fall of "blue stone" exposing fissures running up into the overlying sandstone (11).

The cause of an outburst from the floor or roof is not far to seek. Given that there exists a stratum near the seam holding great volumes of gas under pressure; given, again, that that stratum is separated from the seam by an impervious bed which is not too readily fractured, and the conditions are suitable for such a burst. The relief of pressure occasioned by the extraction of the seam leads to the buckling of the impervious bed

through the accumulation of gas behind it; a cavity is thus artificially formed, and, when a break occurs, the accumulation is ejected into the workings. The Coxlodge instance just referred to occurred in bord-and-pillar working; but the majority of outbursts from the floor and roof have taken place in longwall mines. The longwall method, especially when faces are kept straight and packing-material is scanty, is apt to encourage the formation of these big gas-blisters. The best-known precautionary measure is to prick the blister by boring into the pavement or roof (as the case may be), and if that operation be systematically carried out it is generally successful in quietly draining off the gas. Boreholes were employed with this intention by Mr. J. Easton about 1850 at the Hebburn Colliery; they were used in the eighties at Aldwarke Main, and succeeded in stopping outbursts from the floor, which before then had been common at that pit (10); and, again, Mr. A. R. Sawyer, writing in 1886 with especial reference to North Staffordshire mines, refers to the frequent practice in fiery seams of boring holes from 3 to 6 feet deep in the roof to liberate the gas, and to diminish the risk of heavy falls (12). In other places where gas is apt to collect in blisters in the roof, and where the top coal is left on, the latter can only be kept up with great difficulty until the gas is drained off by boreholes; then the roof becomes sound.

III.—Outbursts from the Solid Coal.

A few of the greatest outbursts of this kind have already been mentioned. I propose in this section to look more closely into the circumstances of these discharges, and, as immensity tends rather to paralyse than to assist enquiry, it has been considered preferable to devote attention to occurrences on a more moderate scale. Their characteristics are best dealt with under heads, thus:—

The Cavity Theory.—It seems certain, despite allusions here and there to "cavities of gas in the coal" and the old miner's expression "bags of gas," that in no British outburst from the solid of which we have record has there been in the seam anything of the nature of an open cavity holding gas under pressure: the gas is contained in the coal. Even if such cavities can be conceived as originally existing, it is very improbable that they could remain long under the pressure to which all but shallow seams are subject. That open cavities are not impossible in shallow seams, however, is clear from the observation of Mr. E. A. Simcock (14), who found open pockets some 20 feet in length, containing gas under pressure in a thick seam in Upper Assam at a depth of 120 feet.

Physical Character of Coal Ejected.—In the kind of outburst now dealt with coal is blown out with the gas. In almost every case the ejected coal has been found to be in a fine state of division, a proportion of it being excessively fine dust; it is often described as "sooty," "danty," or "mushy"; and fragments crumble under the pressure of the finger and thumb. There is no doubt that the softness of the coal is essential to these outbursts, and that the condition of loose aggregation or fine state of division of the particles exists prior to, and is not merely the result of, a burst; it is, in fact, a cause and not an effect of the irruption. This has often been demonstrated when boring advance holes in a seam subject to these occurrences; the tool has been felt to enter suddenly into soft coal, and then dust and gas—and sometimes the drill—have been ejected from the hole (15) (16).

Where these outbursts occur the coal is invariably very dry. I propose to return to this matter at a later stage; its significance has not been realized. What appeared at first sight to be an exception to this rule was the Bedford Colliery outburst of March, 1918 (17). It occurred at a depth of 1,500 feet in a heading in the Trencherbone Seam. Water with gas was first observed to issue from the floor; then there was a violent blast from the centre of the face; 26 cwt. of fine coal were shot out, leaving a cavity 8 by 3 by 3 feet. Gas and water continued to pour out of the cavity for a long time after the burst. The coal and dust discharged from the opening, however, were quite dry.

Geological Conditions.—Another important characteristic of these occurrences is that they are usually associated with faults or other disturbances of the strata. There were irruptions from the side of faults or from their close neighbourhood in the Bensham Seam, Jarrow Colliery, in 1830 (18); at Wallsend in 1835 (5);* at Haswell, where the burst took place against three small parallel troubles and discharged about 35,000 cubic feet of gas (19); at Glencraig, Fife, in 1902 and 1905; and at Valleyfield in 1911 (16). A number of outbursts have happened at a depth of 1,100 feet at the Metropolitan Colliery, New South Wales (15); and they were all in the vicinity of faults or igneous intrusions.

At Ponthenry the irruptions occurred after driving through a "want" and upon entering the thickened seam bordering the want. Geologically the circumstances were remarkable. Fig. 1, redrawn from Mr. G. Rob-

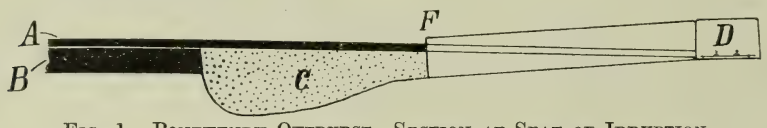


Fig. 1.—Ponthenry Outburst: Section at Seat of Irruption.

lings' paper (1), is a section along the heading in which the first blast occurred on February 27th, 1920. The seam (Lower Pumpquart) is of anthracite; normally it consists of two portions, namely, the top coal (6 inches) *A*, and the bottom coal (2 feet 8 inches) *B*. The depth was 900 feet. A slant *D* (7 inches per yard) had been driven through the nip-out. The top coal was found to be continuous and unaffected, but the bottom coal was absent in the slant. The heading *DF* had been turned off to explore the extent of the want. It immediately encountered the bottom coal, which was in a very friable condition, "yielding nothing above peas, and even those could be crushed between the fingers." The face had reached *F*, 22 yards from the slant, when the outburst took place with great violence; a large quantity of gas was discharged, and 170 tons of fine coal were shot out into the heading and slant. A further 110 tons had been disturbed inside the original face of the heading. A cavity was left where the friable coal *C* had lain, the cavity extending to the rise from the line of the section in a roughly pear-shaped form. There was a similar outburst in the same area of disturbed ground on November 20th, 1920. Mr. Roblings was kind enough to send me a sample of the friable coal ejected on the latter occasion. Every piece large enough for inspection was slickensided all over: there seems little room for doubt that the material was smashed up and squeezed into the position it occupied under intense lateral pressure. The extraordinary feature is that the upper coal did not suffer the same treatment.

* W. N. and J. B. Atkinson, however, considered this to have been a dust explosion (see their *Explosions in Coal Mines*, page 141).

A considerable amount of danty coal may be produced by a fault of insignificant size. Thus at Valleyfield (16), where 90 tons of coal were blown out, the originating disturbance was a slip of only 6 inches throw. The strength of a fault, however, cannot always be judged by the throw, as the movement is seldom in the vertical plane only.

The rôle of the fault or other disturbance (with a reservation in the case of a dyke) appears merely to be that of a comminuting agent. A dyke, besides converting the coal in contact with it into a loose sooty mass, may also harden the coal at a little distance from it; the sooty mass may then act as a reservoir for gas, and the hard coal retard the rate of escape of the firedamp from that reservoir into a road or face approaching it. This seems to have been the state of affairs at the Metropolitan Colliery, N.S.W., where outbursts occurred on piercing the zone of hardened coal which acted as a dam to the gas.

As a seam is followed, the coal may alternate between compact and friable without the intervention of either dyke or fault. If the seam is dry and gassy, an outburst may take place when, on cutting through a portion more compact and impervious than usual, a part is exposed which is softer and more friable than usual. A number of outbursts in the Rams Mine, Pendleton Colliery, at depths of from 2,500 to 3,500 feet, were of this character; each occurred after a place had been driven through a rib of altered coal called "hard knots" (3). The long series of bursts that took place at the Broad Oak Pit between 1885 and 1892, at depths exceeding 1,500 feet, were also of this kind; there were areas of very soft coal surrounded by strong ribs containing fireclay (15). Roof-weight played a part here, as the irruptions were accompanied by "bumping."

Change of Temperature.—The sudden expansion of a mass of compressed gas, when accompanied, as in the case of these outbursts, by the performance of a great deal of external work in forcing back the atmosphere and in giving kinetic energy to the extruded coal, must result in a drop of temperature. Such an effect has been recorded in Lower Silesia, where sudden outrushes of carbon dioxide bring about a lowering in the temperature of the surrounding coal (20). At Ponthenry the ejected material was found, during removal, to be warm—not cold. A thermometer inserted in the heap 3 feet in front of the workmen registered up to 138° Fahr. The heating cannot have been a direct effect of the outburst, and—although the material was anthracite—appears to have been due to oxidation. This view is supported by the fact that, according to the tests of Mr. C. A. Seyler, the gas subsequently found to be occluded in the soft material contained nearly 63 per cent. of carbon dioxide, while that extracted from the normal anthracite of the seam contained only 6·4 per cent. of that gas (1).

Effect of Mode of Working.—Almost without exception, outbursts of gas from the solid have occurred either when driving winning headings or when "working in the whole" in bord-and-pillar mines. Experience indicates that the best precautionary measure in seams liable to these accidents is to work advancing longwall and to avoid pushing forward the faces too quickly. A wide, straight face advancing slowly gives a chance for the gas to drain quietly from the coal; it goes a long way towards obviating the creation of a dangerously steep pressure gradient in the coal immediately in front of the face. So far as this particular risk is concerned, hand-cutting becomes safer than machine-cutting, and in some Continental mines prone to these outbursts coal-cutting machines

are prohibited; they carry forward the face too rapidly. A regular discharge of gas from a face is a sign of safety, and a cessation of that discharge is an indication of danger.

As is generally known, boring in advance is often resorted to in seams of this kind, although there are several cases in which that process has yielded disappointing results; in faulty ground, however, it is advisable to riddle the faces with boreholes.

Explosions following upon Outbursts.—An outburst of firedamp has seldom been followed by an ignition of the gas, especially since the ventilating furnace became obsolete. Paradoxically enough, the bigger outbursts are safer in this respect than the smaller ones, as, with the former, the expulsion of gas and dust is so violent that all flame-lamps in the district are at once extinguished. At Ponthenry, and in other cases, every lamp in the seam was put out by the concussion. In the majority of the fatal accidents from gas outbursts that have occurred in this country, the victims have either been smothered by fine coal or have succumbed from lack of oxygen.

IV.—The Ponthenry Outbursts Regarded from the Chemical Standpoint.

Mr. C. A. Seyler made ultimate analyses of the material ejected at the first Ponthenry outburst (February, 1920) and of the normal anthracite of the seam. Thanks to Mr. G. Roblings, I am able to quote the results, which are as follows:—

	Normal anthracite (dried). Per cent.	Outburst coal (dried). Per cent.
Carbon	89·95	90·49
Hydrogen	3·20	3·18
Oxygen plus nitrogen	1·82	2·72
Mineral matter	5·03	3·61
Totals	100·00	100·00

The difference between the two analyses is inconsiderable. A like result was obtained when a similar comparison was made in connexion with the Shelton Colliery outbursts (14).

Dr. R. Lessing has been kind enough to undertake, for the purposes of this paper, the chemical examination of the material from the second (November) Ponthenry outburst. As the following proximate analyses show, the proportion of ash in the outburst material was much greater than that from the normal anthracite of the seam:—

	Normal anthracite. Per cent.	Coal from outburst. Per cent.
Moisture	1·34	1·30
Volatile matter (excluding moisture)	6·12	6·16
Fixed carbon	90·28	83 70
Ash	2·26	8·84
Totals	100·00	100·00
Nitrogen	1·09	1·02
Colour of ash	Chocolate brown with large white patches.	Light maroon with large white particles.

Excepting for the ash-percentage, the two samples were, chemically speaking, almost identical.

Dr. Lessing proceeded to investigate the nature of the incombustible matter in the two coals. He also immersed ground samples of the coals in a liquid of 1·5 specific gravity, and examined the ashes of the

" float " and " sink " portions. He observed that the ashes of the " float " fractions were much alike, and consisted to a large extent of highly ferruginous particles of web-like structure very similar to the ash of vitrain and clarain.* The following conclusions may be drawn from Dr. Lessing's work :—

(1) The greater proportion of incombustible matter in the outburst material was accompanied by an increase in density; or, in other words, by an increase in the percentage of the coal which sinks in a liquid of 1·5 specific gravity.

(2) The substance of higher density that was thus introduced into the outburst coal occurred mainly in particles of relatively large size—a fact indicating that the invading substance was mixed in by mechanical action rather than carried there in solution.

(3) The ash of the " sink " fraction of the outburst coal—the part which contains most of this invading substance—was very high in acid-insoluble, high in silica, and comparatively low in iron.

Mr. Roblings observes that the soft " rashing " (3 inches) which usually separates the top and bottom coals was not present at the seat of the outburst, and that it had apparently been mixed up with the soft coal. The churning-up with the coal of the rashing, and, perhaps, of some of the fireclay floor of the seam, would explain both the extent of the increase in the ash-percentage and the chemical character of the ash as revealed by Dr. Lessing's examination.

V.—The Ponthenry Outbursts Regarded from the Physical Standpoint.

From the physical point of view, outbursts of firedamp or carbon dioxide from the solid coal constitute a problem in gaseous adsorption. " Adsorption " is the name now given to the property possessed by some porous substances, notably the denser kinds of charcoal, by virtue of which they are able to compress upon their surfaces a relatively large mass of gas. These adsorbents are traversed in all directions by capillary passages, the first purpose of which is readily to convey the gas to all parts of the solid. The larger capillaries or pores may be seen under the microscope in charcoal and some kinds of coal. A channel which is so large that it may be detected by the microscope plays, however, but a small part in the process of adsorption; the gas is mainly held upon the surfaces of passages which on the average are of a width not many times the diameter of a molecule of methane. Recent work on gaseous adsorption—particularly that of the last two years—has added much to our knowledge of its mechanism; it is now known, for example, that the attraction exercised by a surface of cocoanut charcoal, such as that used for box-respirators, is so intense that the gas-molecules are drawn to it and packed upon it under a pressure of the order of ten thousand atmospheres. This adsorbed layer of gas is excessively thin, but with a well-activated charcoal the area of the molecules of the solid (or, more properly speaking, of the polymers of the solid) which is exposed to gas is so enormous that the charcoal can fix or hold in this way several times its own volume of a gas like nitrogen or firedamp, even at ordinary atmospheric pressure. It is interesting to find that as far back as 1868, long before the word " adsorption " was coined and before the nature of the phenomenon had received much notice, the late Sir

* The names now given to the bright portions of banded bituminous coal, vitrain being without recognizable structure, and clarain containing plant-*débris*.

Isaac Lowthian Bell (7) called attention to the power of charcoal to absorb gases; he suggested to mining engineers that coal might possess similar properties, and that they might eventually be found to lie at the root of the outburst problem.

In 1916 Mr. J. Ivon Graham read before this Institution a paper dealing with the solubility of gases in coal (21). He experimented with methane, carbon monoxide, carbon dioxide, nitrogen, and hydrogen, and showed *inter alia* that coal, even at 30° Cent., may take up at atmospheric pressure over three times its volume of methane. Although not pursuing the enquiry at higher pressures, he was, I believe, the first to obtain definite quantitative evidence of the immense capacity of dry coal for gas, and especially for an easily-condensible gas such as carbon dioxide. In the discussion of that paper, Dr. Haldane pointed out how this latter fact went a long way towards explaining the outbursts of carbonic acid in French collieries.

It was discovered during the war that coal, like charcoal, can be "activated"—that is to say, its adsorptive power can be greatly increased by artificial means; and towards the end of the war an activated Pennsylvanian anthracite ("bachite") was produced, and was one of the materials used for anti-gas purposes by the United States Government. In this country a briquetted mixture of a charcoal-dust and coal-dust was manufactured for the same purpose. It is unnecessary here to discuss the processes of activation; it is sufficient to say that in the cases of charcoal or colloidal silica they appear to do nothing more than disrupt the elaborate polymers from which these substances are built up, and so create a wider expanse of surface, and a greater development of passages of molar dimensions, available to the gas (22). The artificial activation of coal involves, in addition, the driving-off of all volatile ingredients—a process which opens vents of microscopic and ultramicroscopic size, and, by doing so, reduces the resistance of passage of a gas into or out of the material. In this connexion, however, it must be observed that the soft coal from the second Ponthenry outburst, although, as will shortly be seen, showing signs of partial activation, does not contain less volatile matter than the normal anthracite of the seam.

To study the problem experimentally, a steel gas-cylinder of 1·2 litres water-capacity was filled with dried outburst coal, which was well shaken down within. The weight of coal introduced was noted. A stop-cock was then screwed and soldered into the cylinder neck, a small plug of asbestos-wool being first placed in the neck under the cock to prevent coal-dust from being blown out. The cylinder was then charged with compressed dry firedamp, so as to restore, as nearly as possible, the *status in situ* of the material before the outburst. The firedamp was obtained from South Wales; its content of methane (almost 98 per cent.) is much the same as that of the firedamp of the Pumpquart Seam at Ponthenry, which on analysis showed 98·8 per cent. of methane.

A throttle-valve, provided with a pressure-gauge, was screwed to the cylinder; the latter was placed in a vessel of water to keep it at uniform temperature (15° Cent.), and the gas was allowed to flow slowly out through a meter. The gauge and meter were carefully tested beforehand. From time to time the flow was stopped, a short interval was allowed to elapse, and the gauge-reading was taken.

It will be clear that gas discharged in this way will come in part from the coal and in part from the interstices existing between the particles of coal: it is also obvious that when the coal was *in situ* there were no such open interstices; their influence had, therefore, to be eliminated. A number

of determinations were made of the specific gravity (1·50) of the material;* this figure enabled the actual volume of the solid material in the cylinder to be found, and the difference between the volume of the cylinder and that of solid coal gave the interstitial space. It proved to be 37 per cent. of the total volume. As the gas expanded from that space in accordance with Boyle's law, it was an easy matter to correct the volume of gas discharged for the amount extruded from the interstitial space. The results were then set down in graphical form (curve *B*, Fig. 2), so as to indicate the relationship between the gauge-pressure in atmospheres and the volume of firedamp (at normal pressure and 15° Cent.) dis-

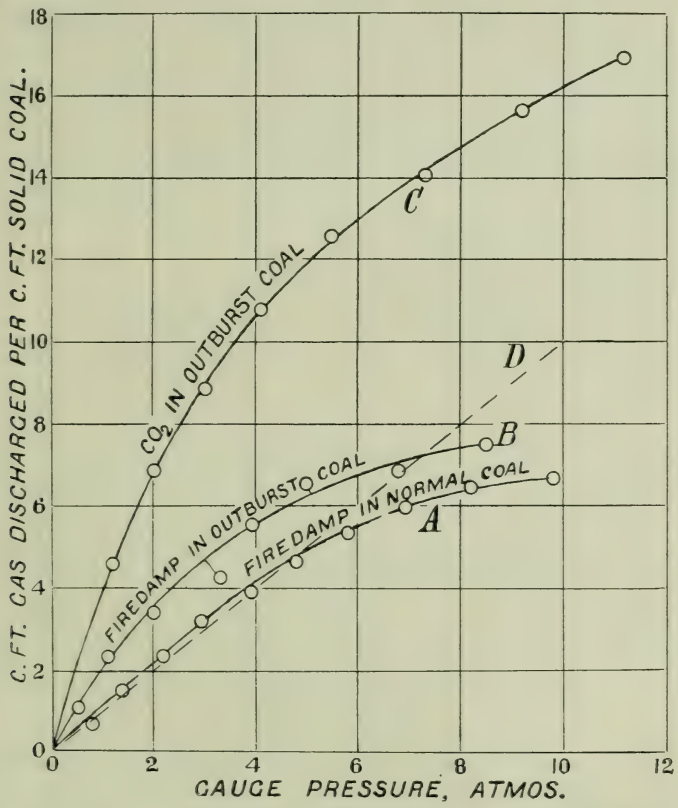


FIG. 2.—PONTHENRY COALS: ADSORPTION OF GAS UNDER PRESSURE.

charged by a cubic foot of solid coal. The experiment was repeated, using carbon dioxide (see curve *C*, Fig. 2).

A quantity of the normal anthracite was then ground to a state resembling that of the outburst coal; it was dried and placed in the cylinder, and the test again carried out with firedamp (see curve *A*). The line *D* expresses the relation between pressure and volume of gas discharged from an open space of 1 cubic foot.

The graphs show the outburst coal to be, per unit volume, a better adsorbent of firedamp than the normal anthracite of the seam. For

* If the coal had been a more active adsorbent, the determination of density by the usual method of water-immersion would have been liable to considerable error, owing to the fact that in such a case the water is intensely compressed in the thin layers in actual contact with the solid (22).

apparently the first time we meet here with a substance that has undergone a natural process of activation to a small though definite extent. Whether this feature is special to the Ponthenry coal, or whether it is the rule with the material ejected in these outbursts, can be settled only by examining the coal from many other such bursts.

Curve *B* also shows that, with pressures up to 7 atmospheres, the outburst coal held, ready for almost instantaneous discharge when the pressure was relieved, a quantity of gas greater than would have been held by an open cavity of the same volume.

Though unfortunately we do not know the pressure at which gas exists in the solid coal at Ponthenry, a rough estimate of the volume of gas blown out at the first outburst may be made if we may assume that that pressure probably lies somewhere between 4 and 8 atmospheres. This outburst threw out or disturbed 280 tons of coal, which would have a volume of about 7,200 cubic feet *in situ*. An open cavity of that size would have released 57,600, 43,200, and 28,800 cubic feet of gas on a fall of pressure to zero (gauge) from 8, 6, and 4 atmospheres respectively. Containing, as the pocket did, the soft coal of the outburst, it will be found from line *B* of Fig. 2 that the following gas-volumes would be emitted at the pressures stated :—

Firedamp released from 280 Tons of Ponthenry Coal.

Gauge-pressure. Atmospheres.	Volume released (measured at 15° Cent.). Cubic feet.
4	40,320
6	48,390
8	53,570

If the conditions had been those of the French and Silesian collieries where carbon dioxide is discharged, the coal would have held a much greater volume of gas (see curve *C*), amounting, in fact, to about 107,000 cubic feet at 8 atmospheres and 77,800 cubic feet at 4 atmospheres. The greater adsorption of carbon dioxide is due mainly to its critical temperature being above that of the mine, while that of methane is much lower. Hence the coal is able, by the pressure of adsorption, to liquefy (and then still further compress) the carbon dioxide in the very thin films which lie in actual contact with the molecules of the solid; but methane at 15° Cent. is incapable of liquefaction in this way.

It is important that the coal ejected by these outbursts from the solid is dry. The adsorptive power of coal—or charcoal for that matter—is greatly reduced by moisture; so much so, indeed, that bursts of that kind are not to be feared in seams in which water exudes with gas at the faces. The entry of water for the first time into a virgin seam containing gas adsorbed under pressure, an effect which may result from the working of a neighbouring seam, would bring about an evolution of gas, and, unless there were channels of relief, an increase in the pressure of gas in the seam—a fact which may have a bearing upon the problem of sudden outbursts from the floor and roof.

To sum up, sudden outbursts of gas and coal from the solid are due to the co-existence of four factors, namely: (1) the presence of gas under considerable pressure, (2) the presence of a mass of disintegrated coal which is loose enough to move under a sudden relief of pressure and to set free almost instantaneously the greater part of the gas adsorbed in it, (3) the absence of water in the soft coal, and (4) the employment of a method of working which affords little opportunity for the gas to drain quietly from the soft coal; or, as an alternative to the last, the presence in the seam, and surrounding a soft zone, of ribs of low permeability

which prevent or interfere with that drainage. It has also been shown that in the instance especially studied the phenomenon of "activation" played a part in increasing the volume of gas adsorbed by the loose coal. Activation is, however, not an essential factor, as normal coal can adsorb sufficient gas to cause outbursts if the necessary conditions obtain.

I wish to thank Mr. George Roblings, Agent and Manager of the Ponthenry Collieries, and Dr. R. Lessing for the help they have so readily given.

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(3) "Outbursts of Gas and Coal at the Morrissey Collieries, British Columbia," by James Ashworth, *Trans. Inst. M. E.*, 1904-1905, vol. xxix., page 56; discussion, page 62.

(4) *Le Grisou*, by H. le Chatelier, page 38.

(5) "Colliery Explosions and Rescue Appliances," by W. Galloway, *Practical Coal Mining*, 1907, vol. v., page 65.

(6) "Instantaneous Outbursts of Fire-damp," by Ichon and Lombard, *Trans. Inst. M. E.*, 1891-1892, vol. iii., page 1070, abs.

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(8) "Narrative of Sudden Outbursts of Gas in Collieries working the Barnsley Thick Coal and the Silkstone Coal, in the Neighbourhood of Barnsley," published by the Midland Institute of Mining, Civil, and Mechanical Engineers, 1879.

(9) "Report of an Outburst of Gas in the Haigh Moor Seam at Whitwood Collieries," by W. G. Jackson, *Trans. Inst. M. E.*, 1889-1890, vol. i., page 27.

(10) "An Outburst of Gas at Houghton Main Colliery," by J. Jarratt, *ibid.*, page 29.

(11) *A Treatise on the Ventilation of Coal Mines*, by Robert Scott, 1868, page 19.

(12) *Accidents in Mines*, by A. R. Sawyer, 1886, page 85.

(13) "Outburst of Natural Gas at Kissármás, Transylvania, by L. de Lóczy, *Trans. Inst. M. E.*, 1911-1912, voi. xliii., page 585, abs.

(14) "Outbursts of Coal and Gas in the Cockshead Seam, Shelton Colliery," by F. E. Buckley, *ibid.*, 1906-1907, vol. xxxiii., page 313; discussion, page 320.

(15) "Instantaneous Outbursts of Fire-damp and Coal, Broad Oak Colliery," by John Gerrard, *ibid.*, 1899-1900, vol. xviii., page 251; discussion, page 258.

(16) "An Outburst of Coal and Fire-damp at Valleyfield Colliery, Newmills, Fife," by Henry Rowan, *ibid.*, 1911-1912, vol. xlii., page 50; discussion, pages 127 and 274.

(17) "Instantaneous Outburst of Coal and Gas at Bedford Collieries, Leigh," by F. N. Siddall, *ibid.*, 1917-1918, vol. lv., page 210.

(18) *Modern Practice of Mining*, by R. A. S. Redmayne, 1911, vol. iv., page 42.

(19) *Papers on the Theory and Practice of Coal Mining*, by George Fowler, 1870, page 43.

(20) "Accidents caused by the Escape of Carbon Dioxide in Coal-mines," by B. Werne, *Trans. Inst. M. E.*, 1914-1915, vol. xlix, page 837, abs.

(21) "The Permeability of Coal to Air or Gas, and the Solubilities of Different Gases in Coal," by J. Ivon Graham, *ibid.*, 1916-1917, vol. lii., page 338.

(22) "Adsorption of Gas by Charcoal, Silica, and other Substances," by H. Briggs, *Proc. Roy. Soc.*, A, 1921 (in course of publication).

Dr. R. Lessing (London): Since my name has been mentioned in connexion with the paper, perhaps I may refer to the analyses which I had the pleasure of carrying out for Prof. Briggs. I was very much interested in studying the difference in the ash-contents, which became apparent after I had done the proximate analysis of the two coals. I have here specimens of what I obtained, and I may explain that the figures as stated in the paper are really not all that can be seen from the two sets of samples obtained—that is, the unchanged anthracite and the outburst coal. Particularly the latter, the outburst coal, represents a set of average figures consisting of a light and a heavy portion. The same applies to the anthracite, but to a very small extent. In separating the two, the anthracite gives only 1·8 per cent. of a heavy or "sink" fraction, whilst the outburst coal gives 30·4 per cent. Therefore, the analytical data given for the outburst coal represent really those of a mixture of 70 per cent. of what is practically identical with the original anthracite, and 30 per cent. of the heavier and higher ash-containing material. The appearance of the ashes themselves shows that the 70 per cent. in the outburst coal are of the same kind as the anthracite itself. The analysis of the ashes of the two "flood" fractions is practically identical, although the appearance of the coal is different. As has been explained by Prof. Briggs, it is of a "danty" or "mushy" appearance, whilst the anthracite shows clear-cut bright particles.

One peculiar feature of the ash of the anthracite and light fraction of the outburst coal is that it is very similar in appearance to the ash which we usually obtain from what is now called the "vitrain" and "clarain" of bituminous coal—that is to say, the bright portion of bituminous coal. It has a fluffy light structure; and although one must be careful in pronouncing definite opinions upon the subject, it is likely that in this case, as in the case of vitrain, the ash represents to a large extent at least the original plant-ash, while the ash in the heavy fraction represents rock-fragments and the shale portions, which are quite different in appearance and in composition. The composition of the ashes from the heavy particles may be indicated by stating that they contain as much as 81 per cent. of acid insoluble material, whilst the ashes of the light material and of the anthracite—and they show quite good agreement—are something of the order of 52 or 53 per cent. of acid insoluble material, showing that a great deal of it is soluble either in water or in acid.

So much for the ashes, from which, in the main, it seems that the outburst consists of anthracite, and, as has been indicated by Prof. Briggs, the heavy portion in the outburst is most likely composed of, or represents, that part of the thin seam of "rashing," which I understand is present above the solid anthracite but has been cleared away in the region where the outburst coal came from.

The question now arises whether the generation of gas is the cause or the effect of the disintegration of coal, whether the two phenomena are at all related to one another, or whether it is simply a corollary that where the gas is generated the breaking-up of the coal must occur. It is hardly likely from what has been indicated by Prof. Briggs that the breaking-up is caused by the gas, because even where there is no outburst soft material is found under similar conditions. It seems to me, however, that there must be some relation, and that the disintegration of the coal is due to some up to now unknown chemical factor. That the gas which comes off should produce it is not very likely, but there

must be something, and from experiments which I have been carrying out lately, on rather different lines, but with similar results, I have no doubt that it is possible to produce by certain treatment a soft powder from what is usually known as hard coal. What the nature of the breaking-up is it is very difficult to say to-day in our state of ignorance of the chemical composition and the general constitution of coal; but it seems to me a most important line of investigation to follow, because it must be somewhat related, and is most likely closely related, to the liberation of gas from coal in the ordinary way. Where that gas cannot escape, owing to geological conditions, it will be collected under pressure and may cause these outbursts, but the generation of the gas must be on somewhat similar lines even in the solid coal.

That, in connexion with the anthracite, brings up one important problem, namely, the anthracitation of bituminous coal. We know very little about this. Most of the information is contradictory to a degree, and it seems that the anthracitation of coal is closely connected with this generation of gas from bituminous coal. One point which seems to corroborate such an opinion is that anthracite stands high in the order of activation for the adsorption of gases. I found this morning a reference to a paper by Prof. A. Freire-Marreco in 1875,* in which the order of evolution of gas from coal when heated in a vacuum to 100° Cent. was as follows:—Bituminous coal, 0·7 volume; steam-coal, 2·9 volumes; and anthracite, 7·5 volumes. This shows that anthracite is really much more active, retains more gas, and, therefore, if one may say so, molecularly it is more porous than bituminous coal. This would indicate that it must have lost something, say, in the nature of gas, as has been the case with outburst coal.

Prof. Henry Louis (Newcastle-upon-Tyne): I want to call Prof. Briggs's attention to the fact that in his bibliography he has apparently overlooked the most important paper of all, namely, on "Instantaneous Outburst of Carbonic Acid in the Mines of the French Central Plateau" by J. Loiret, read at the International Mining Congress held at Düsseldorf in 1910.† I think that if Prof. Briggs had read that paper he would probably be inclined to modify somewhat some of his views. It states rather the opposite point of view to that which he would lead us to believe. It has been found that the best way to overcome these difficulties is to forbid all hand-hewing. The method there advocated is to get the coal by firing very heavy shots. The coal is drilled, the hole charged, and an order given for every one to get out of the mine, and then very heavy shots are fired electrically.

Dr. R. Lessing: There is one point I wanted to mention, namely, the question of adsorption at atmospheric pressure and under high pressure. The experiments referred to in this paper, which are very valuable, and which I believe confirm the general experience on those lines, were done under high pressure, and show that gas was released after the high pressure had been applied. It seems to me from the practical mining engineer's point of view that it is a very important point to try and find out how much gas can be adsorbed and retained by the coal under atmospheric pressure. I believe at present it is very difficult, if not

* "Further Notes on Recent Examinations of Coal-gases," *Trans. N.E. Inst.*, 1875-1876, vol. xxv., page 41.

† "Les Dégagements instantanés d'acide carbonique dans les mines du Plateau Central français," International Congress, Mining Department, Düsseldorf, 1910, page 132.

impossible, to say in regard to any coal how much gas it does contain, either methane, or, after weathering, oxidized products like carbon monoxide or carbon dioxide, and until it is possible to get at the rock-bottom position and until we are able to say "here we have a coal which has no gas adsorbed at all in any shape or form," we shall not see quite clearly what the position is.

Dr. J. S. Haldane (Oxford): I am very much interested in this question, and I think the Institution is indebted to Prof. Briggs for bringing the facts before it in so convenient, clear, and striking a form. I was particularly struck by Sir William Atkinson's abstract of M. J. Dougados' account of the huge outburst at the Nord d'Alais Colliery, Gard, in 1907, to which Prof. Briggs refers in his paper. I do not know whether the members realize exactly what happened on that occasion. There had been a number of small outbursts of carbonic acid in the pit which was being sunk at the time, and also in mines in the neighbourhood—formidable outbursts of carbonic acid and dust—and, therefore, they were working with great precautions, with, in fact, the precautions which Prof. Louis mentioned, which are all given in full in M. Dougados' paper, and also in Sir William Atkinson's abstract. They had forbidden work with the pick and were firing shots from the surface. They were sinking down they did not know into what, and they had penetrated one or two thinner seams. A round of shots were fired in shale, which was above another seam they were going for. They did not know what sort of seam it was, and it turned out to be one 60 feet thick! The overman who fired the shot from the surface noticed immediately the shot was fired a rush of air coming up the downcast shaft. It had reversed the air-current. At the same time he heard an awful noise going on down below, apart from the shot. He knew what had happened, because that sort of thing had occurred before, and he called out to the men on the pit-bank to run, and he ran also. They all got safely away except three men. One man did not run when he was told, and two others were inside the engine-house, and did not run. They were all overwhelmed by the gas. It spouted up, a sort of volcano of dust and gas, to twice the height of the headgear, over 100 feet, and then came down again, and spread all round the country for some distance, covering everything with dust. There were 3 feet of dust on the roof of the engine-house, and the whole ground round was spread thick with it. The men who bolted away got in front of the stream of gas, which was flowing like water over the country, and all escaped except the three men I have mentioned; but a number of animals were killed—dogs and hens, etc. Many people in the houses near were half asphyxiated, but I suppose that they got into the upper stories and somehow or other escaped this flood of gas, so that no one else was killed. The choking feeling of the carbonic acid was felt about a mile away from the pit, and the flow of gas went on for twelve hours. It was a most dramatic occurrence. It was not a sudden explosion; it was like a volcano. When they got down to this enormous thick seam, of the existence of which they were not aware, they found that when it was cut into, the boundary between the coal which was softened and the ordinary hard coal of the seam could be seen quite distinctly, and it was found to be close to a fault, as is always the case. There always seems to be a fault near this softened coal. I have no doubt whatever that Prof. Brigg's explanation is correct—that the coal is softened by a shearing strain due to the fault.

As I pointed out in the discussion on Mr. Graham's paper some

years ago*, the explanation of the occurrence is clear. The gas can come off quite readily and easily from the disintegrated coal, whereas solid coal holding exactly the same amount of gas in solution will not give it up. In a more recent paper Mr. Graham pointed this out in a very striking way by the result of cutting into a big solid block of coal that had stood in the colliery office for forty years in order to see what gas there was still there.† There was plenty of methane, and very little oxygen had got in. The coal was quite unoxidized inside, or very little oxidized. It shows how very difficult it is for gas to come out of solid coal when it is once in.

Mr. Graham showed that coal was extraordinarily airtight. It is not porous in any ordinary sense, and it will not let gas or anything else pass, or at least only very slowly. But this loosened softened coal does let gas out easily. That raises the question of how the dust is produced in these explosions of dust and coal. Mr. Dyer Lewis, the Inspector of Mines in South Wales, had drawn my attention to the Ponthenry outburst, and I asked him to get a sample of the softened coal—not the coal which had been blown out as dust, but the original softened coal near the wash-out—and a sample was sent to me. We were just experimenting on it when Prof. Briggs's paper came out. We had no doubt whatever that adsorption explained the whole of these phenomena, as has been pointed out already; but what we were interested in was how the very fine dust is produced. I have very grave doubts as to whether it is there before the explosion. What we wanted to see was whether, when coal is thoroughly saturated with gas and the pressure let off suddenly, it will fly into fragments in the same way as when the cork of a champagne bottle or a soda-water bottle is suddenly withdrawn the contents fly into the air and scatter. The experiments are not yet finished, but I hope that Mr. Graham will report on them soon. I rather suspect that to a certain extent it must be the case that fine dust is not there. What is there is softened coal, softened by the shearing stress, and that simply bursts, as it were, when the pressure is taken off suddenly. The whole process is like a devil's cauldron; more and more of the coal is drawn in, and it behaves like a volcano for a long time.

At the Ponthenry outburst the miners said that going past it was like going past a winnowing fan. The stuff was still blowing out at a great rate, and dust with it, and this continued for a long time.

There is one point which is not cleared up, namely, the source of the carbonic acid. Ordinary coal in this country never does give off any considerable quantity of carbonic acid, so far as is known—that is to say, the carbonic acid is not there. There is always a little, but sometimes only traces of it in the gas that comes out; sometimes there may be 3 or 4 per cent. I do not know what the source is in the mines in the South of France, but it may be some volcanic source—that is to say, the carbonic acid comes ultimately from the disintegration of carbonates by silica at high temperatures underground, or something of that sort; but I do not know. The whole matter is very peculiar, and nothing like it has been met with anywhere in this country.

Of course, if there was carbonic acid under pressure in the rock oozing up continuously, the coal would catch it, adsorbing or dissolving it, and the coal would gradually become saturated with carbonic acid at high pressure. The amount taken up is enormous, as both Prof. Briggs's

* *Trans. Inst. M. E.*, 1916-1917, vol. lii., page 353.

† *Ibid.*, 1919-1920, vol. lviii., page 32.

experiments and those of Mr. Graham have shown. Coal is a tremendous reservoir of gas.

The definite discovery of this adsorption is very interesting. It gradually dawned on us at the Doncaster Laboratory. It was Mr. Winmill who first came across it in experiments on the amount of oxygen which is taken up by freshly-dissolved coal. He found that there was apparently much more oxygen taken up than was due to ordinary oxidation—to chemical change—and when he measured this amount he found that it varied with the pressure of the oxygen. Then he came to the curious conclusion that coal, instead of having a specific gravity of about 1·5 or 1·4, as everyone hitherto had assumed, is really about twice as heavy, and that the rest consisted of holes—that it is a porous substance. He was misled because the solution or adsorption of oxygen varies exactly with the partial pressure. It is exactly the same thing as the solution of gas in a liquid, and follows Henry's law in the same way. Mr. Graham went further, and investigated the whole matter thoroughly and quantitatively, and found that nitrogen and oxygen were both adsorbed in harmony with Henry's law of solution of gases in liquids. It comes in a way to the same thing as Boyle's law. That explained at once a great many results which had been obtained. It was always an utter mystery to me why coal-dust, collected and then put in a vacuum and exhausted—there are a number of experiments on that—gave off so much oxygen and so much of different gases; particularly, the amount of oxygen got from the dust lying along the roads was mysterious. The quantity was so small as to be of no importance whatever practically; but theoretically it was an absolute mystery until we knew that coal takes up ordinary gases in this way. That, at any rate so far, makes all these outbursts clear.

As to what adsorption is—I rather prefer the old-fashioned term "solid solution" myself—and what the nature of the process is, I do not think people have yet agreed. I am clear in my own mind that the process of solution in a solid and solution in a liquid are fundamentally the same, and that it is due simply to molecular attraction in both cases, but a good many people would disagree with me. Mr. Winmill, curiously, was misled by the word "adsorption," and the way in which it has been used as denoting a kind of solubility which gives a bent curve such as you see in Prof. Briggs's experiments with carbonic acid. The adsorption of oxygen was in a straight line, and was so also with nitrogen and hydrogen. That misled Mr. Winmill at first until Mr. Graham got on the track of it and cleared the whole matter up.

The figures given by Mr. Graham in his paper answer Dr. Lessing's question. If Dr. Lessing will look at the figures, he will see the answer to his question about gas-less coal and so on. There were various samples, exhausted most carefully till there was no gas left, and then an adsorption curve was determined directly. Mr. Graham has done an immense deal of work on these adsorptions at varying pressures up to 30 atmospheres, and he was hoping to bring them before the Institution, but during the last two or three years the amount of routine work to be done at the Doncaster Laboratory has been great. Mr. Graham was acting as colliery chemist as well as research chemist, and that has kept back the publication of these papers very much. But they are beautiful curves, about which I hope Mr. Graham may say something.

I am very glad that Prof. Briggs has brought up this question, because it raises the subject of adsorption with hands and feet, so to speak, in a concrete way, so that the mining community can understand the interest and even the practical importance of it. They want to under-

stand what they are doing when they are dealing with gases coming off; they want to understand why they are working longwall if they wish to avoid this sort of thing. With regard to the cooling effect of the evaporation of gas when it comes off—methane, for instance—at the working-face, Mr. Graham has done a great deal. It has been done for the Temperature Committee. In taking temperatures at the coal-face you go into a layer which is full of fissures that extend quite a long way from the face, and the gas comes off and cools down the whole mass of coal. It is all to the good of the miner; I mean that the presence of methane is on the whole a great blessing to the miner, as it seems to me. It cools him down and improves the ventilation enormously, and it makes him a healthy and a happy man, and only now and again does it send him up into the air!

Mr. John Roberts (Abertridwr): Some time ago I collected a number of coals from the vicinity of faults, and actually in the fault-planes. I also collected samples of the same seams at some distance away from the faults. In examining these coals, with the object of trying to get some information as to the origin of anthracite, I found that the coal from a fault always behaved differently from that from the unfaulted seam. One effect on the faulted coal was that it had lost some of its coking properties; another was that the volatile matter had decreased. In one case the volatile matter of the normal seam was about 24 per cent., and that from the faulted coal 19 per cent. The normal coal expanded on coking, and gave a porous spongy centre; the faulted coal gave an absolutely uniform coke, and did not swell. It appears to me that the volatile matter from the seam has been driven off as the result of faulting, and if the conditions are not favourable for the escape of the volatiles, then the gases will accumulate and finally exert an enormous pressure. Probably some action of that sort has taken place in the case of the outburst at Ponthenry. There are other profound changes evidently taking place in the neighbourhood as a result of a disturbance. One of the samples I collected was taken from a place in the seam which seemed to have been crushed. It was not an ordinary roll in which the floor and the roof rises. The seam had given way, but the roof remained practically level, and the seam above this roll had been compressed from 3 feet 3 inches to about 1 foot 9 inches in thickness and was crushed. But some profound change must have taken place in the coal, because on drying it in a steam-oven a tarry substance was given off and deposited on the porcelain dishes and on glass vessels at 100° Cent. Of course, that is a very unusual occurrence.

With regard to Dr. Lessing's remarks on anthracite, this original investigation was made to throw some light on the origin of anthracite. He suggested that the theories were contradictory. As a matter of fact, they need not be. If I wanted to produce artificial anthracite I should take advantage of both the dynamic theory as to its origin and the theory put forward by Dr. Strahan. In fact, artificial anthracite can be made in that way, and if any member would like to see photographs of this stuff they may do so. Anthracite has been produced by dynamic agencies. Some of these faulted coals, for example, have been thoroughly carbonized and converted into coke in the plane of the fault. In my opinion the main cause is geological, but it has produced chemical results in its action.

Mr. Robert McLaren, M.P. (Airdrie): I think we must all conclude from the remarks of the last two speakers that the theory of adsorption

of gases by coal has still a long way to go before we can satisfy ourselves as to exactly how the phenomenon is brought about. With regard to the enormous outburst of carbon dioxide mentioned in the paper, it strikes me that probably a mistake has been made, because my experience of these outbursts has been that there is a great deal of firedamp liberated, which acts precisely the same when there is no ventilation as carbon dioxide does, and it would not surprise me in the least if it were shown by and by that in the case in question it was not carbon dioxide but pure firedamp. The pity is that an analysis of the gas itself was not obtained at the time.

Dr. HALDANE: If it had been firedamp, it would have gone right up to the sky.

Mr. ROBERT MCLAREN: I am not sure; it may have been a mixture. In any case, I suppose we must take it for granted that it was carbon dioxide and leave it at that.

I find that Prof. Briggs speaks about these outbursts taking place in the roof as well as in the seam. I have had considerable experience of these outbursts, and whilst most of it has been confined to occurrences in the coal, I distinctly remember one case where the outburst took place in the roof. It was in the Hamilton district, and the openings were about 10 feet wide. The men working at one of the faces heard what they considered to be an unusual noise a few yards from the face; they came out and examined the roof, and while they were doing this a sudden burst took place from the roof a short distance in-bye from where they were. Fortunately, the seam was worked with safety-lamps, and before the men were able to get to the shaft every lamp was put out by the excessive amount of gas given off. I think, if I remember rightly, the length of the hole was about 10 feet parallel to the working-road and was cut off by the side of the stoop, and 4 or 5 feet high in a blaes roof. In the course of a few minutes the whole ventilating system was deranged, and right from the shaft to all the faces in that pit the air was fouled. Fortunately, the men got out. Some of them were a little shaken by swallowing the gas. It was a most extraordinary occurrence, because while there had been some slight outbursts in connexion with the coal, there had never been hitherto any outburst in the roof.

I observe, too, that Prof. Briggs alludes to the cavity theory, and I think that there can be no doubt at all that in some cases gas does lodge in little cavities. When the 5-foot seam at the Glencraig Colliery, Fife, which is mentioned by the author, was opened out, a great deal of gas was given off. I made it a point to go there frequently, because I was in the position of Inspector of Mines and was anxious to put in safety-lamps. I went to see exactly how the ventilation stood and what gas was given off. It was of frequent occurrence at the working-face for slabs of coal to be forced out by gas-pressure, and in every case immediately after the slabs of coal came out there was a little flash at the miners' lights, but the gas was instantly carried away by the ventilation. As there were no accumulations of gas, I could not very well compel the management to put in safety-lamps.

Every time they came across a "back," the coal suddenly burst out. The miners rather enjoyed that, because they did not require to use the pick: the gas-pressure did for them what the pick was intended to do.

In putting down some boreholes recently in a place where the seam is virgin and has never been worked, the bore-rods suddenly went down the hole for a distance of about 3½ feet. That appears to have been a cavity,

because all round the whole district the coal has never been worked, and what is true in connexion with these cavities, even what we discovered in the boring, may be equally true in connexion with gas-cavities. I think Prof. Briggs has been very wise in leaving the subject as it is, because I am of opinion that cavities will be found to be a source of these gas-pressures in the various seams.

Prof. Briggs refers to gas being discharged at Glencraig in 1902 and 1905, and at Valleyfield in 1911. I happened to make enquiry into the very serious accident at Glencraig, and the whole details were given in my Report for 1902, but it may not be out of place to amplify what has been said by Prof. Briggs, and to give you an idea of how the outburst occurred. It is the same seam as that to which I alluded where little pockets of gas lay in the coal. The section was in a narrow place and two faults had beeen met with, and I may state that in almost every case known to me where outbursts of any size at all have taken place they have occurred near a fault.

With regard to Mr. Robert's remarks as to the volatile matter in coals near a fault becoming very low, may I suggest to him that perhaps it may be due to the fact that there was some whin in the vicinity.

Mr. John Roberts : There were no whins in this case. It was in the eastern part of the South Wales Coalfield.

Mr. Robert McLaren : We usually find in Scotland that where there are whins the volatile matter is decreased. One of these faults was 9 feet wide, and the other was smaller, and the men were working inside when suddenly an outburst of fine dust took place. Here I may say that in this case there can be no doubt at all that what was thrown out was fine coal-dust, because I myself on going into the hole afterwards found a large quantity inside. There were no large pieces of coal; in fact, the dust was so fine that one of the men at the face who was about to fill a hutch was overwhelmed at once and buried entirely with the fine dust whilst still standing on his feet. The amount of gas given off was very large. The gas-pressure went right against the intake air and some distance up, and the tail of the gas was ignited by a naked light, which caused a slight explosion in other parts and suffocated two men farther back.

Some idea of the pressure coming from the outburst can be obtained by the fact that in a very short time a column of air equal to 3,596 pounds was displaced against a water-gauge of 1·75 inches. That case was examined by me personally, and I have no doubt whatever that what occurred there was a tremendous pressure of gas right behind the fault; the coal apparently had been disintegrated in such a way as to become very fine indeed, and when the pressure was released by the men working on the face the coal came out suddenly and in a body.

At Valleyfield also we had a big outburst when the 5-foot seam was newly opened up, and three men were suffocated by the outburst of gas. One hundred and ninty tons of coal—some was not very fine, of course—was thrown out, and in order to ascertain the pressure—this, I think, is very important—for a long time afterwards, and to relieve the pressure in other parts of the coalfield, bores were put in regularly, and whenever they were put in the gas came out at a certain pressure. I myself some years before had made some experiments in some of the various seams where gas was known to exist; I bored holes and took the pressures. In every case we discovered with all the coals we examined that after standing so many hours they gave an indication of pressure behind, some

greater and some less. I think it is perfectly fair to assume—without exception, I think we may say—that although we cannot very well detect it, every coal-seam gives off gas more or less. In order to illustrate that, I may tell you that in a certain seam in Lanarkshire, which has never in that district been known to give off gas, and which was worked for over thirty years with naked lights, in 1902, I think, there was very low atmospheric pressure, the glass was abnormally low, and when the man who had been fireman there for many years was going round the face that morning with his naked light he suddenly lighted some gas. He got such a fright that he came up the pit and never went back again. He was so sure that gas could not possibly be seen in that pit, as it had never been known in the district, and everybody was surprised that gas had been detected in the seam.

I conclude, therefore, after a long experience, that without exception there is gas in every seam. It may not be there under pressure, as in the case of Valleyfield, and in the same condition as described by Prof. Briggs, but I think it is there nevertheless.

I am not a strong advocate for safety-lamps, but there are cases where they are an absolute necessity. Whilst it is necessary where there is much gas that we should have safety-lamps, still with a good system of modern ventilation, even where the seams give off gas more or less, there does not appear to be any reason whatever why a man should not have the very best light he can get to help him to work the coal.

Mr. John Roberts : Prof. Briggs has opened up an interesting line of investigation. There may be some relation between the dust produced by faults and the occurrence of explosions. In South Wales several explosions have occurred in a limited zone, and most of those have occurred near the anticline; at Cilfynydd, at the Great Western Colliery, a mile or two away, at Risca, Llanbradach, and Senghenydd, these pits are situated very close to the anticline. I am wondering whether, as the result of the frequent faulting of the strata and the very fine dust produced, that dust will be more inflammable than the dust normally produced in coal. Prof. Briggs may have facilities for carrying on an investigation of that sort.

Mr. J. Ivon Graham (Birmingham University): This is a most interesting subject both from the practical and theoretical point of view, and as Dr. Haldane and Prof. Briggs have both referred to work which I did some years ago, I would like to compare some of my more recent results on the high-pressure adsorption of gases with those of Prof. Briggs. In the first place, has he any record of the fineness of the dust with which he carried out his high-pressure experiments given on page 126. The fineness makes, of course, a great deal of difference in the rate of evolution of the gas, or conversely the rate of adsorption. An experiment which I carried out some years ago on the adsorption of firedamp, carbon dioxide, and nitrogen up to pressures of over 30 atmospheres gave figures similar to those of Prof. Briggs, but in general I got somewhat higher results. Take, for example, the firedamp given off by normal coal as shown in Fig. 2. The results I obtained at a pressure of 10 atmospheres when working at a temperature of 11° Cent. worked out with dry coal at approximately 16 cubic feet of gas per cubic foot of coal, as against Prof. Briggs's 6·7 cubic feet. Shortly after the paper I gave in 1916 I found that the presence of moisture in the coal affected its adsorptive qualities very considerably. For example, the Barnsley soft coal, when dry, took up something like 250 cubic centimetres of methane per 100 grammes

of coal, whereas the moist coal took up only about 90 cubic centimetres under the same gas-pressure; so that there was a considerable difference as the result of the presence of moisture in the coal.

I notice that Prof. Briggs states that in his experiments a short interval was allowed to elapse after releasing the pressure and before taking the gauge-reading. In experiments which I carried out I found that I had to expose the coal to the high-pressure gas in many cases for at least a week before I obtained a constant pressure-reading. A very slow adsorption took place, and when the pressure was released and the volume that was given off estimated, I found that I had to leave the experiment for a long time before I got a constant reading on the pressure-gauge. When the pressure was released, a rapid evolution took place, and then the gas was given off for some hours afterwards until equilibrium was obtained between the concentration of the gas in the coal and the concentration in the gaseous phase.

Unfortunately, the curves which I have obtained have not been published yet, but I hope to give them in the form of a paper shortly. They are rather straighter than those of Prof. Briggs. It just struck me that the explanation of this is the possibility that in his experiments sufficient time may not have been left between the release of the pressure and the final gauge-reading. His results would consequently give more of a bent curve.

With regard to carbon dioxide, the results I obtained were very similar to those of Prof. Briggs at 10 atmospheres; but I got rather more carbon dioxide than he has got in the outburst coal. I wonder whether Prof. Briggs could not have got rather more gas out of his coal than he has stated in his paper by allowing a longer time to elapse after releasing the pressure and before taking the gauge-reading?

The influence of moisture is very interesting, and, of course, as Prof. Briggs states, if you have a dry coal saturated with gas under high pressure and then wet that coal, the pressure will have to be very greatly increased in order to keep the same amount of gas in the moist coal.

The point of the cooling effect of gas is very interesting, and just recently, as Dr. Haldane has pointed out, in connexion with the determination of strata temperatures, we have carried out a large number of experiments on the actual rock-temperatures met with in coal-seams. There we are up against a difficulty in getting the true temperature at the longwall face. In certain instances we found that in the case of gassy pits, even when the coal-face was bored to a depth of 20 feet, the temperatures obtained indicated that a considerable cooling of the whole mass of coal had taken place as a result of the evolution of gas. The gas when it is adsorbed produces a certain amount of heat, and when it is liberated a certain amount of heat is absorbed from the coal.

On the question of boring in order to release gas, owing to the impermeability of solid coal (and this question of impermeability is proved by repeated borehole experiments), there will be very little gas-flow from a borehole in the solid face. This we have found by inserting special tubes arranged so as to give a gastight joint and measuring the gas-flow from the boreholes. Immediately one strikes a break, however, there is a big increase in the flow of gas.

From the point of view of the release of gas from the coal in advance of the face, boreholes would seem to be of little use unless one strikes breaks, by means of which the gas can be drained into the borehole.

There is an interesting point in connexion with the question of gas in cavities and of gas coming from an accumulation of dust. In cases

where the gas coming off from the coal contains small quantities of higher hydrocarbons—occurrences occasionally met with—if a blower of gas be encountered it might help one to forecast whether this is from a cavity or from an accumulation of dust if frequent samples of the gas coming off are taken. If a change from pure firedamp in the first blowing off to gas containing higher hydrocarbons be found, I should be inclined to suspect an accumulation of dust, because one finds in the laboratory that if one takes a lump of coal and grinds it up the first gas to come off is practically pure methane, whereas the last traces of gas to be given off frequently contain a large proportion of higher hydrocarbons. It seems to me that if an analysis be carried out in that way, an indication might be obtained as to whether the gas was coming from a cavity or from an accumulation of dust. It seems a great pity that in the past we have not had more particulars of the analyses of gases from these outbursts. I think we may find in the future that the gases produced in coal-mines may have an important bearing on the actual conditions under which the coal is produced. It seems to me quite feasible that under certain conditions of decay of organic matter, and the production of coal from such, carbon dioxide may be produced in some cases. I was just thinking of some experiments which were carried out by the Swedish chemist Bergius some years ago in the production of artificial coal at high pressures and high temperatures. He worked up to 100 atmospheres pressure and from cellulose got a coal-like substance, and at the same time gas was produced, both carbon dioxide and methane. We usually find in coal-mines that it is practically all methane, but in certain circumstances there may probably be a certain amount of carbon dioxide. These are experiments which I think, combined with an accurate knowledge of the analysis of gases which are given off normally from these blowers, would help to increase our general knowledge as to the formation of coal.

Sir John Cadman: This is a very important subject and one which naturally lends itself to scientific investigation. After what has been said, I hope that Mr. Graham will not content himself with simply expressing his views in a discussion on this paper, but that we shall have the advantage at a later date of a paper from him on the work which he has done on the subject.

Prof. Briggs has given us an account of the history of certain of these phenomena and an excellent record of his own investigations; but, if I may be allowed to be critical, he has omitted to record a great deal of information which is to be found in the Annual Reports of H.M. Inspector of Mines.

Mr. McLaren has referred to the outburst at Glencraig. It was my privilege then to be working under Mr. McLaren, and I recollect a great deal of the data upon which he gave his judgment. I remember taking part in the investigation of the Glencraig outburst, and one point which occurs to me is that the cavity which had been formed was not smooth: it had the appearance of rough coal, but when you put your hand on the wall it had rather a soapy, graphitic feeling.

Another case in which I had personal contact was at the Shelton Deep Pit in North Staffordshire. That was an extraordinary occurrence, with many points of similarity to the Glencraig outburst. The same curious characteristics on the sides of the cavity were observed there. I remember trying to compare the amount of *débris* that had been thrown out with the size of the cavity, but the figures were incomparable.

Mr. R. W. Dron (Glasgow): The question of anthracite has been raised in the discussion. I would like Prof. Briggs to say whether he thinks that anthracite is more liable on account of its activation to create the conditions for those sudden outbursts, and, if so, will he explain why the outbursts which are given in the appendix to his paper are practically all confined to bituminous coal and not to anthracite?

With reference to Mr. Roberts' remarks on the origin of anthracite, those of you who are interested in that point may remember that in Scotland we have conditions of anthracite formation which are, I think, rather unique. In Scotland there are anthracite-seams which quite evidently were metamorphosed by the action of heat due to intrusive dolorite. In a paper I wrote recently I went a stage further.* I pointed out that not only anthracite produced in this way was altered, but, in addition to that, seams which were put down as non-coking coal in their original condition have been altered into coking coal by the action of the whin. What puzzles me in these cases is this: the volatile matters have apparently been driven off; but the percentage of ash is not increased. We have not, of course, the very same seam under the very same conditions, so that we could say: "There is a seam which has 3 per cent of ash when it is bituminous and still 3 per cent. of ash when it is anthracite"; but, all the same, the general inference from what we have in Scotland is this—that while the volatiles have been driven off the percentage of ash has not been proportionately increased.

Another point which I would like to suggest to those who are investigating the subject is: what becomes of the volatiles? There is absolutely no evidence in the surrounding strata of any tarry matter which might have been driven off if the heat had been strong enough. It may be that the heat was very slight for a long period of years, and that the volatiles were driven off in such a manner as would not involve the production of any tarry matter, but it is a little puzzling where those volatiles have gone; they have disappeared entirely. The seam has remained, as far as one can see, of its original thickness and with the original percentage of ash.

All scientific investigators are very keen on destroying the coal-trade completely by finding out the source of atomic energy. It would be rather curious if by investigations into this subject in our own coal-mines it is found that the energy producing those outbursts is closely allied to atomic energy. Are we approaching something which is going to be very useful to humanity, but a bad thing for those dependent on the coal industry?

Capt. C. B. Platt (Doncaster): Prof. Briggs states that at Ponthenry the ejected material was found during removal to be warm—not cold—and that a thermometer inserted in the heap 3 feet in front of the workmen registered up to 138° Fahr. It would be interesting to know whether the seam in the immediate neighbourhood of these outbursts is more liable to self-heating than the coal in the remaining part of the seam. From the above statement it would appear that the dust ejected from the blow-hole is very liable to self-heating. I would like to know whether Prof. Briggs has found that fires have occurred during these outbursts owing to breaks in the coal caused by the upheaval.

Mr. George Roblings (Ponthenry) wrote: I would like to refer to

* "The Occurrence of Coking Coal in Scotland," by R. W. Dron, *Trans. Inst. M. E.*, 1917-1918, vol. lv., page 61.

some of the conditions existing in the Lower Pumpquart Seam in which occurred the outbursts of gas referred to by Dr. Briggs.

The seam has a normal thickness of 3 feet 2 inches, and is the lowest workable seam in the Lower Coal-Measures of the anthracite district. No other seam in the series varies so much in thickness, continuity, and friability of the coal as does this one. There are areas where the roof and floor are apparently perfectly conformable, without even a trace of coal existing; in others the coal thickens to as much as 14 feet, and is of excellent quality; while other areas of thin coal are to be found of so friable a character as to be useless.

In some cases the thick coal is composed of oblique layers from floor to roof, each layer being about the normal thickness of the seam, with the top clod tailing down between the layers, as shown in Fig. 3; while in other cases the seam is perfectly normal, but overlain by the downwardly tilted edges of the beds forming the roof. In many places widely apart there is a thin leather-like bed $\frac{1}{2}$ to $\frac{3}{4}$ inch thick between the coal and roof. This bed is similar to that referred to by Prof. Fearnsides as being one of the indications of horizontal movement.*

Outbursts of gas have been recorded in several places in this seam, principally, however, in the Gwendraeth Valley, of comparatively small extent, but invariably in areas of soft coal. There are, however, numerous areas of soft coal which do not show evidence of any internal pressures as of pent-up gas. Several of these outbursts have occurred in

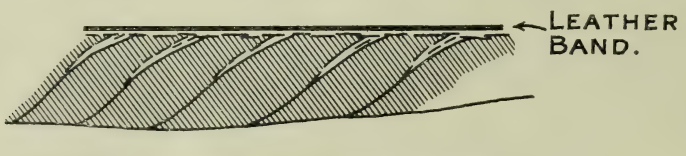


Fig. 3.—Showing Coal with Tailings of Clod.

patches where there is no apparent fault. In the case under notice, which is the largest outburst that has taken place, the area of soft coal comprises a trough about 20 yards wide running in a north-westerly direction. The affected area is shown in Fig. 4.

On the north-eastern margin of this trough the bottom coal had been gradually nipped out, while the top coal retained its regularity and hardness over the whole area. The south-western margin was formed by a step in the floor bringing the coal back to its normal thickness, but unusually strong in character. The line of demarcation between the soft and the strong coal was well marked and in line with the step in the floor, but did not, however, run into the top coal.

The coal in the trough showed ample evidence of having been subjected to intense pressure, the contorted appearance suggesting lateral pressure, and the slickensides on the coal suggest an horizontal movement from the north-east.

There must have been two movements, one of which was more or less vertical and of a local character and affected the floor alone. The slickensides on the face of the step indicate a descending inclined movement. This movement by the bending of the floor probably caused the nip-out, and the horizontal component of the movement would roll over this coal, crushing it in the process into the hollow formed by the sinking floor, thus changing the coal into a condition which would enable it to

* "Some Effects of Earth-movement on the Coal-Measures," etc., *Trans. Inst. M. E.*, 1915-1916, vol. l., page 573; and vol. li., page 409.

adsorb the gases and retain them until such time as the resisting portion of the coal-seam was worked away and permitted the gases to burst out.

It is difficult to estimate the age of this disturbance or movement. There is undoubted evidence that horizontal movements in this seam between the coal and roof occurred in places wide apart. The effect, however, is not identical in every case. There is also evidence in the neighbourhood of the effect of the Caledonian movement along the north outcrop of this field, which exerted a compressive force from north to south, and undoubtedly caused the numerous overthrusts found in this district.

From the similarity in the direction of movement to the above, in the case under notice, I would not think it unreasonable to attribute it to the same movement, if I could account for the cause of the break in the

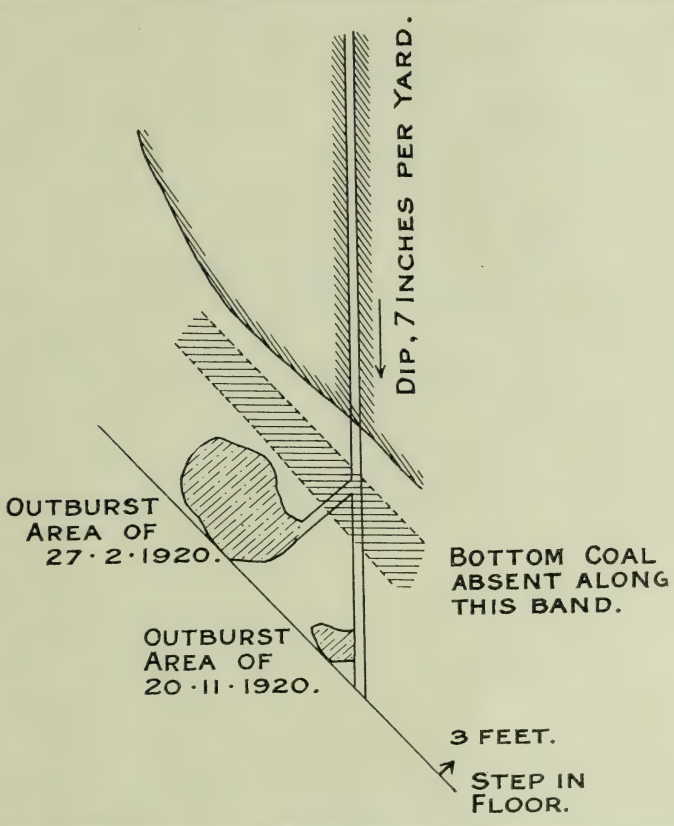


FIG. 4.—SHOWING THE AREA OF THE OUTBURSTS IN THE LOWER PUMPQUART SEAM.

floor. I prefer to attribute it to the same cause as Prof. Fearnsides attributes the rock-faults of Tinsley Park—that is, to local contraction of the underlying rocks.

In the matter of boring, it was found that the gas was not released from any substantial distance surrounding the hole, thus indicating that there was an absence of communication or passages through the coal. Even when working the coal after the face had been practically riddled with holes, great caution was necessary in the working, as the pressure did not appear to have been released.

The conclusions I have drawn are: (1) that the outbursts are due to the inability of the soft coal to resist the bursting pressure exercised by

the pent-up gas, and (2) that the soft coal is caused by horizontal movements, there being nothing to show that the original material differed in character.

If it were possible to work all these soft-coal areas by longwall, very little would be heard of them. It has been found necessary to work the soft coal in this seam in several places which were obviously unprofitable, in order to enable other places in good coal to be properly ventilated and worked with safety, rather than run the risk of outbursts in a narrow airway in a piece of soft coal, with the chance of drawing serious outbursts of gas, and closing up all workings and entombing the men on the in-bye side. I am of the opinion that, where practicable, the working of this class of coal by longwall is a better safeguard than even boring.

Prof. Henry Briggs (Edinburgh): With regard to self-heating, the question last raised, this coal is anthracite and is not normally liable to self-heating. I thought this instance of self-heating was unique in the experience of the mine, but Mr. Roblings tells me that some heating took place years ago in a heap of duff at the surface. He has also noticed a similar increase of temperature in outburst coal from the same seam at a neighbouring colliery.

Mr. Dron raises a number of most interesting points which have behind them a wealth of practical experience. At the same time, I do not think that this direction of investigation is going to assist us in making use of atomic energy, or even of finding out more about it. The manifestation of energy which is called an " outburst " is on a very much smaller scale per pound of material than the type to which he alludes; it is more of a molecular than an atomic character.

There is no question that anthracite holds more gas than other kinds of coal, and for that reason might be expected to be more prone to outbursts. Probably, however, the greater strength of anthracite makes it less apt to be reduced to the soft state necessary before an outburst can take place.

With regard to the remark as to the insufficiency of the instances given, I did not attempt to make the bibliography at all exhaustive, and, as Prof. Louis and Sir John Cadman have pointed out, it could be extended.

M. Loiret's paper, to which Prof. Louis refers, though limited to a description of the French carbon-dioxide outbursts, is interesting as furnishing other instances of outbursts from the solid. Its chief value to us, as Prof. Louis has indicated, is in the reference to the method of breaking down the coal by heavy charges fired from the surface—a method to which I alluded in my brief description of the Nord d'Alais eruption. Shot-firing from the surface, however, does not prevent these occurrences, though it obviously reduces the risks attending them. My remarks on the rate of advance attempted to deal with measures aiming at prevention; in this respect there is nothing in Loiret's paper to make me change my opinion.

Mr. Graham's remarks as to his own work interest me very much indeed. The question of moisture is a very difficult one to anyone who is working on these materials. They do not let go their moisture very easily. If you try to make a coal lose all its moisture, you run the risk of driving off something else, which changes its properties. In fact, coal can be made to hold considerably more gas by simple heating. I will not guarantee that the coal was absolutely dry; I have got beyond the stage of guaranteeing that any absorbent is absolutely dry. In all probability,

however, the coal was as dry as it was in the seam. Even with charcoals, one cannot guarantee that they are always dry; a little moisture sticks to charcoal at 900° Cent.

Mr. Roberts has related how a coal, subjected to long-continued drying at 100° Cent. *in vacuo*, may lose some of its higher hydrocarbons, and Mr. F. G. Trobridge in 1906 published results (*Jour. Soc. Chem. Ind.*, Vol. XXV., page 1129) indicating that, at that temperature, a considerable amount of the higher homologues may be evolved. Any action of the kind increases the activation of the sample. On the other hand, as Mr. Graham states, insufficient drying results in a decrease in the amount of gas that can be got in.

The question of the interval of time has been touched on. The interval was short as compared with Mr. Graham's, the usual practice being to fill a cylinder with gas and allow it to stand over night before any pressure-measurements are taken, and then to let it out very slowly and, as the paper states, to allow a short interval, which used to amount to something like half-an-hour, to elapse before the gauge is read. That was the result of preliminary trials to ascertain what the effect of short and long intervals was, and, as Mr. Graham was the first to point out, the larger the size of the coal-particles the longer the interval requires to be. This material was able to give off gas comparatively rapidly, or there could have been no outburst.

Dr. Haldane has raised the question as to whether the substance is soft before it begins to give gas out, or whether it becomes soft during the emission of gas. One knows by experience what is the result of differing from Dr. Haldane in any view; at the same time, my bias just now is rather the other way: I think that the softness was one of the causes rather than the effect of the sudden emission of gas.

Dr. Haldane: It was not whether it was soft, but whether it was there as a fine powder. There is no doubt that it was soft, because you could see afterwards that it was soft.

Prof. Briggs: How can you have it as a fine powder when it is a solid mass of coal?

Dr. Haldane: You have lumps which, if squeezed, will easily be disintegrated. The stuff which comes out seems to be a fine dust.

Prof. Briggs: It is not a fine powder, though. There are bits in this Ponthenry stuff which are as big as hazel-nuts, but their condition inside shows that the coal has undergone the action of rubbing *in situ*. It seems rather reasonable to suppose that that action so broke up the coal as to allow it to get rid of its gas quickly. Dr. Haldane and I may both be right. There may be a further amount of breaking-up by the actual emission of the gas.

Capt. Sinnatt: Could it be the fusain?

Dr. Lessing: I have been considering this point. It has not the general appearance of fusain, and I think the ash is rather too low for fusain. We do not quite know how fusain was produced or what it really means. But it has not the structure of fusain. With regard to the size, I have some figures which show that in the "float" portion of the outburst there was 12 per cent. remaining on a 10-mesh sieve, 39 per cent. on a 6-mesh, and only 17 per cent. in the "sink" portion. It is comparatively coarse.

Dr. Haldane: Was that the dust that was picked up in the mine, the dust that had been blown out, or was it the coal?

Prof. Briggs: It was the outburst material as found.

Dr. Haldane: It was not simply the dust itself?

Prof. Briggs: No; it was of all sizes. A considerable part was excessively fine. Boring in solid coal does not seem a very good way of preventing these outbursts, although in some cases it has been successful. It was not unsuccessful, as Mr. Graham suggests, because of the impermeability of the coal, but rather that it gave off gas so readily when the soft coal was struck that the coal was forced into the borehole and choked it, and "corked" it, so to speak.

Mr. McLaren has given instances of outbursts in Fife, and the results of the examination of an interesting occurrence in the Hamilton district, which was an outburst from the roof. The significant point is that it was in bord-and-pillar working and not in longwall working. Such an occurrence is unusual. Usually the outbursts from the roof are in longwall working, because there is a wider expanse of new roof standing exposed at any one time.

Mr. Robert McLaren: There can be no question of roof pressure in that case, because it was near the coal-face; it must have been due to gas entirely. There was no weighting at all.

Prof. Briggs: I think the cavity question will have to remain undecided until we collect more evidence. My own view is against it very decidedly. I think that everything is explained without that theory, and that, indeed, the coal itself is more efficacious than a cavity in emitting gases. It will hold in a state available for emission a greater quantity of gas than a cavity could under the same pressure.

Mr. Roberts raises a number of interesting issues. His remarks as to the changes he has observed in coal at faults may have a bearing on the outburst problem in bituminous seams. In the Ponthenry case, however, with the exception of the ash-content, the composition of the outburst material and of the normal seam was virtually the same. I doubt whether it is permissible to accept the theory of localized zones in which the gas is pent up in a seam under higher pressure than elsewhere. If circumstances arise, in the manner Mr. Roberts outlines, resulting in the development of increased pressure, no coal exists which is impervious enough to prevent the distribution of the gas and the re-equalization of the pressure in the course of geological time.

My thanks are due to all who have joined in the discussion, and especially to Dr. Lessing and Mr. George Roblings, who have supplemented my paper by much useful information.

DISCUSSION OF MESSRS. BEET AND FINDLEY'S PAPER ON "THE BETTER UTILIZATION OF COKING SLACK."*

Mr. John Roberts (Abertridwr): The authors were quite justified in bringing forward a proposal to separate coal into two fractions, because there might be an advantage in separating bright from dull coal for certain purposes. I have already hinted at one, in the discussion on

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 213.

Prof. Briggs's paper, namely, the artificial production of anthracite; but, for the purposes which they propose, I do not think it is really necessary. In the first place, they assume that by separating bright coal from dull coal, on account of the fact that bright coal has a stronger coking property than a dull coal, they will get a better coke as a result. I am inclined to favour the opposite view. I do not mean that if the bright coal is separated from the dull that a better coke will be obtained from the dull coal than from the bright coal; but I would not like to say that you would get a better coke from bright coal than if you took the coal in its natural condition. It does not necessarily follow that because you have a coal with a high coking index it is going to produce the best coke. In my experiments on coal I have found that it is generally better to reduce the coking index in order to obtain a superior coke. If one wishes to get the best light on the coking process, one of the best ways is to take a charge of coal and partly carbonize it and stop the operation half-way.

If a charge of coal be put into a crucible and the carbonization stopped half-way, it will be found that there are several zones in that coal. Next to the uncarbonized coal there is a fusion zone, where the coal is just melted; below that is another zone, where the excess binder has been decomposed: that zone is very highly porous, and it is a very bad conductor of heat; below that zone will be found a semi-coke; and underneath that will be a high-temperature coke. In order to obtain good heat-transmission and a uniform product, it is necessary to partly destroy this decomposition zone—that is to say, the excess binder that causes it has either to be utilized or partly destroyed. I have found that if coal be mixed with inert matter such as coke-breeze a much stronger and more uniform coke can be obtained than if the raw coal were used—that is, with normal coking coals that have plenty of binder, like the Yorkshire or South Wales coals. All those coals can generally stand a mixture of from 10 to even 50 per cent. of breeze.

The other object in proposing the separation of these constituents was that they would have a coal which would not swell in low-temperature carbonization. The cause of swelling is the decomposition zone. If coke-breeze be mixed with the coal, the expansion is destroyed altogether, so that it is not really necessary to separate these coals in the way proposed in order to prevent expansion. It is better to take the coal as it is, and, instead of taking this inert matter out of it, I would suggest that inert matter be added to it, in order to reduce the coking index, so that it will not swell on carbonizing at low temperature.

Mr. R. W. Dron (Glasgow): The results of my experiments are quite contrary to that.

Mr. A. E. Findley (Liverpool): My experiments on the commercial scale are contrary to Mr. Roberts' statements.

Mr. John Roberts: I have worked on this question continuously for the last eighteen months, and in every case I have found that expansion can be prevented by an addition of inert matter. The heat-transmission is very much improved. As the coke is practically free carbon, you introduce a conductor into the charge and increase the conductivity of the mass; and heat-transmission curves will show that an increased heat-transmission of 50 per cent. is obtained. I have photographs which show the effect on 200-gramme charges that have been stopped half-way. If I mix breeze with the coal, the whole of this mass is carbonized in fifteen minutes; but without the breeze, carbonization does not proceed any further than about $\frac{3}{8}$ inch.

As regards the crushing strength, if a test-piece—say, 15 grammes—of Durham caking coal be taken and used raw in a crucible, it will be found that the coke will stand a pressure of about 100 pounds to the square inch; but if the coal be mixed with 50 per cent. of breeze, a pressure up to 750 pounds will be obtained.

Mr. A. E. Findley: The paper was written not so much from the theoretical as from the practical point of view. In recent years, because of the continuous strike question, we have fed into the coke-ovens coal which contains from 8 to 10 per cent. of ash, and that means that we turn out cokes having 12 to 14 per cent. of ash. I contend that this ought to be stopped, and that what we want is a better coke, one which will contain less sulphur, less ash, and more calorific value. On the other hand, we do not want to waste our coal-substance—that is, we do not want to send it to the tip. In many cases stuff is being sent to the tip which is inflammable, and the County Council authorities and Urban District Councils take proceedings on account of the heaps being set on fire. What I wanted to do was to get something better than the inferior coke which is being made at the present time, and to separate the coal from the muck, but let the muck contain a fair amount of dull coal and some of the bright coal and all the dirt, so that this muck might go through a shale retort without holding up to any very great extent and yield bye-products in the way of oils and ammonia, especially if treated with steam, as it would be in the shale retort.

Mr. Roberts' remarks simply go to show that if the coal were separated into three components, the middle component, sinking in 1·3 and floating in 1·48 specific gravity, would give better results in low-temperature carbonization where swelling is a great difficulty. In some Yorkshire seams I think that it is the presence of too much dull hard coal in the slack which causes the slack to lose its coking properties.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM JULY 3RD TO JULY 30TH, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
	July.														
Sun. ..	3	0	18′5	17′5	15′5	15′5	18′0	21′5	26′0	25′5	23′0	20′0	18′5	18′5	20′0
Mon. ..	4	1	18·0	16·5	13·0	11·5	13·5	18·0	23·5	25 0	22·0	19·0	15·5	18·0	18·0
Tues. ..	5	0	18·5	17·0	16·0	15·0	16·5	22·5	25·5	25 0	21·5	20·0	19·5	17 5	19·5
Wed. ..	6	0	17·5	16·5	14·5	14·0	14·5	19·5	25·5	26·0	22·0	20·5	20·0	17·0	19·0
Thur. ..	7	1	17·0	17·0	17·5	15·5	15·5	21·0	27·5	28 5	24·0	19 5	19·0	19·0	20·0
Fri. ..	8	1	19·5	19·0	17·5	16·0	16·5	21·5	25·0	24·0	20·5	18·5	16·5	19·0	19·5
Sat. ..	9	1	18·0	20·0	21·5	17·5	16·5	20·0	24·5	25·0	22·0	18·0	19·0	19 0	20 0
Sun. ..	10	0	18·5	18·0	16·0	14·0	15·5	20·0	23·5	23·0	21·0	19 0	19·0	19·0	19·0
Mon. ..	11	0	18·0	18·0	17·0	15·0	15·0	18·5	22·0	23·0	21·5	20·0	19·0	18·5	19 0
Tues. ..	12	0	18·0	18·0	16·5	15·0	16·0	20·5	25·0	24·5	20·5	19·0	20 0	19·0	19·5
Wed. ..	13	0	18·0	17·0	15·5	14·5	18·0	22·5	26·0	26·0	23·0	19 5	17·0	16·5	19·5
Thur. ..	14	1	17·0	19·5	17·5	14·5	13·5	18·5	24·0	24·5	23·0	20·5	19·5	16 5	19·0
Fri. ..	15	1	15·5	12·5	13·0	12·0	15·5	20·5	23·5	23·0	21·5	21·0	20·5	15·5	18·0
Sat. ..	16	1	16·0	18·0	14·0	15·0	18·0	22·0	25·0	23·0	20·5	18·0	17·0	16·5	18·5
Sun. ..	17	0	19·0	20·0	18·5	15·5	17·5	21·5	25·5	24·0	21·0	20·0	20·0	19·5	20·0
Mon. ..	18	0	19·0	19·0	16·0	14·5	15·5	22·0	26·5	25·5	20·0	18·5	19·5	19·5	19·5
Tues. ..	19	0	19·5	19·5	16·5	15·5	17·0	21·0	26·5	25·5	21·0	20·5	19·0	18·0	20·0
Wed. ..	20	0	18·0	18·0	16·5	15·0	17·0	22·0	26·5	25·5	21·5	19·5	18·5	19 5	20·0
Thur. ..	21	0	20·0	19·0	16·0	15·5	18·0	22·5	27·0	24·5	21·0	20·5	20·5	20·5	20·5
Fri. ..	22	0	20·5	20·0	16·5	14·5	17·0	23·5	26·0	25·5	22·5	21 5	20·5	19·5	20·5
Sat. ..	23	1	17·0	16·5	18·0	15·5	17·5	20·5	24·0	23·5	22·0	21·5	20·5	19·5	19·5
Sun. ..	24	0	18·5	17·5	16·5	14·5	15·5	19·0	23·0	23·5	22·0	21·0	19·5	17·5	19·0
Mon. ..	25	0	17·5	18·5	16·5	16·0	16·5	19 0	22·5	23·5	23·5	22 0	19·5	18·5	19·5
Tues. ..	26	1	17·5	17·5	16·5	14·5	15·0	19·0	24·0	24·0	22·5	20·0	15·0	18·0	18·5
Wed. ..	27	0	18·0	17·0	15·5	15·0	17·0	21·5	27·0	26·0	22·5	20·5	19·5	19·5	20·0
Thur. ..	28	0	20·0	17·5	16·0	14·0	14·5	19·0	23·5	22·0	20·5	20·0	18·0	18·0	18·5
Fri. ..	29	1	18·0	17·5	16 5	18·0	18·0	21·5	26·5	23 5	21·0	20·5	19 0	15·0	19·5
Sat. ..	30	0	15·5	16·5	15·5	14·0	15·0	19·5	24·5	24·0	22·0	17·5	18·5	18·5	18·5

Diurnal Inequality (i.e., departure from mean value for day).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
July, 1920	−1′6	−1′5	−2′0	−2′7	−3′8	−4′5	−5′1	−4′5	−3′2	−0′8	+2′0	+4′5
June, 1921	−0·6	−0·7	−1·6	−2·2	−3·2	−3·9	−4·7	−4·6	−3·7	−1·7	+1·0	+3·3
June, 1920	−1·0	−1·5	−2·0	−2·8	−4·2	−4·9	−5·3	−4·9	−3·7	−1·5	+1·6	+4·4

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
July, 1920	+5′9	+6′3	+5′7	+4′0	+2′4	+1′4	+0′4	+0′1	−0′2	−0′5	−1′0	−1′4
June, 1921	+4·8	+5·6	+4·9	+3·6	+2·4	+1·4	+0·5	+0·1	−0·1	0·0	−0·1	−0·6
June, 1920	+6·0	+6·4	+5·6	+4·1	+2·6	+1·3	+0·4	+0·4	+0·2	+0·1	−0·4	−0·6

Mean Value for Month.

July, 1920.	June, 1921.	June, 1920.
14° 30′·5.	14° 20′·0.	14° 31′·0.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The normal value for an hour is the mean declination for that hour in the month, derived from quiet days only, or from all days excluding those of character "2." On a day of character "0" declination at any hour will usually be within about 3′ of the normal. On a day of character "1" the departure from the normal will usually not exceed 5′, but it may occasionally be as much as 10′, or even more. On a day of character "2" the departure from the normal will seldom exceed 20′, but departures of 30′, or even on extreme occasions of 1° or more, may occur.

The above values were obtained from measurements made after "smoothing" the curves.

THE SOUTH STAFFORDSHIRE AND WARWICKSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING.

Held at the University, Edmund Street, Birmingham, July 27th, 1921.

Mr. J. R. FELTON, President, in the Chair.

A vote of condolence with the relatives of the late Sir Gilbert Claughton, Bart., a Past-President of the Institute, was proposed by the President and passed in silence, the members standing.

ELECTION OF MEMBERS.

The following gentlemen, having been approved by the Council, were elected :—

Member—

Mr. A. D. Bowdler, 47, Abbey Street, Green Heath, Hednesford, Staffs.

Associate Members—

Mr. T. H. Stonehouse, Lawnswood House, Hill Grove Crescent, Kidderminster.

Mr. S. O. Hatton, University Club, Edgbaston, Birmingham.

Associate—

Mr. Horace Shaw, Blackbrook Road, Netherton, Dudley.

Student—

Mr. R. F. C. Dubash, The University, Birmingham.

Transfer from Associate Member to Member—

Mr. K. N. Moss, 22, Vernon Road, Edgbaston, Birmingham.

Transfer from Associate to Member—

Mr. A. P. Veale, The University, Edgbaston, Birmingham.

THE PLEXOGRAPHY OF SOUTH STAFFORDSHIRE IN AVONIAN TIME.

By W. WICKHAM KING, F.G.S.

Introduction.—The exploration of the concealed coalfields in the South Midlands is intimately connected with the trends of the ridges and troughs existing before the productive Coal-Measures were laid down, and the subsequent ridging up of these troughs. In relation thereto inferences can be drawn, based on the connected history of the detrital deposits accumulated, from early to late Coal-Measure time, on the flanks of the growing Mercian Highlands, which had their highest summits to the south-east of the same coalfields.

Jukes* recognized that in Coal-Measure time there were three anticlines, comprising South Staffordshire, Warwickshire, and Leicestershire, with the floor of the first-mentioned coalfield youngest, the second older, and Charnwood the oldest. He regarded the Leicestershire to Montgomeryshire area as a narrow promontory, or an island, or a group of closely-connected islands, rising, after Silurian time, perhaps very slowly, and undergoing a very gradual and long-continued process of degradation, and remaining above the waters during a great part of the Old Red, Carboniferous Limestone, and Millstone Grit Periods. He also showed four lines of movements† which Prof. Charles Lapworth‡ designated thus —Charnian S.E. to N.W. and Caledonian S.W. to N.E.; Malvernian N. to S. and Armorican E. to W. Prof. Lapworth regarded the floor of the Carboniferous in South Staffordshire as partly Silurian, in Warwickshire as mainly Cambrian and Uriconian, and in Leicestershire as pre-Cambrian, termed by Prof. W. W. Watts "Charnian," as it is older than the pre-Cambrian of the Lickey and Caldecote.

Prof. Lapworth's views embodied a very irregular Carboniferous floor, for "the ranges of Charnwood and the Malverns, of the Wrekin, and the Longmynd, etc., were apparently already in existence, or had been blocked out in outline." He suggested that "A set of connected ridges —or, at all events, a tract of elevated ground—must have extended across parts of the Midland region during the greater part of Carboniferous times."

Prof. W. W. Watts§ has shown that Charnwood was a great range in Old Red times, forming part of this land barrier, and that the Avonian sea encroached on the lower slopes. For instance, a narrow strip, certainly 11 miles long, of Carboniferous dolomitic limestones occupies the syncline on the south-western side of the Charnwood ridges and wraps round their north-western ends.‖

Dr. Vaughan¶ stated that throughout Avonian time a barrier, which in Visean time shifted steadily southwards, existed between his Bristol

* *Mem. Geol. Surv.*, "South Staffordshire Coalfield," 2nd ed., 1858, pages xi-xiv, 81, 110, 133-135, and 162.

† *Ibid.*, page 163.

‡ *Proc. Geol. Assoc.*, 1898, vol. xv., pages 326-335 and 362-364; and compare *Brit. Assoc. Handbook*, 1913, pages 559, 579-583, 588-590, and 597-599.

§ *Geogr. Journ.*, June, 1903, page 6.

‖ *Coal in Great Britain*, page 194.

¶ *Brit. Assoc. Ann. Report*, 1915, page 429, with map.

or south-western channel and his north-western channel, with the shore-line of the latter channel from Anglesey to beyond Bridgnorth. He treated the Upper Visean shore-line from Anglesey to the Wrekin as "straight." If, however, the district between the Longmynd in Shropshire and Trimpley in North Worcestershire is regarded as consisting of dominant Caledonian anticlines and synclines, athwart the main Charnian direction of the shore-line, it would be in harmony with the Carboniferous beds occupying the synclines at Le Botwood and in the Wyre Forest, the occurrence of thin Carboniferous limestones at Acton Burnell, and on the north-eastern and eastern flanks of the Wrekin, and the marked Caledonian strike of the Devonian area I have examined between the Brown Clee and Trimpley.

Vaughan recognized that in Middle Visean time deposition extended southwards to Leicester; but he did not attempt to determine the shore-line between Charnwood and South Staffordshire.

The Pre-Coal-Measure Sequence.—This sequence in South Staffordshire and in the adjacent Trimpley district is as follows:—

	Feet.
Millstone Grit (age unknown) of Wolseley Park	Not known
Highest Avonian (D^{2-3}) of Fair Oak Pit, with a large unconformity below	182–264?
Devonian * ... ... { Dittonian (at least)	750
{ Downtonian	2,050
Upper Ludlow, as at Lye	65
Lower Ludlow	500
Upper Wenlock limestone, 12–20 (say)	16
Intermediate Wenlock shales	100
Lower Wenlock limestone, 30–42 (say)	36
Lower Wenlock shales	600
Woolhope limestone, 7–15 (say)	11
Woolhope shales (Jukes)	100
Upper Llandovery (as at Malvern)	500
Total of Silurian and Devonian	4,728
Lickey Cambrian quartzite (at Nuneaton 600 feet) ...	?
Lickey pre-Cambrian	?

The Charnian and Caledonian Folds.—My Thick Coal model† visualizes the Charnian and Caledonian folds and faults affecting the Thick Coal, based largely on folds and faults, with those trends, existing and planed down in Avonian times.

The South Staffordshire Coalfield can be regarded as one crust-wave, with a Charnian trend, rising gradually from the north-east to the south-west, with its steepest face and deepest syncline on the south-western side of its highest or Rowley crest. The wave travelled to the south-west, and is composed of three parts, namely:—

I.—*The North-eastern Syncline*, consisting of—

(*a*) The wide Cannock Chase syncline, so much deeper to the north-east, divided from—

(*b*) The higher Tipton to Oldbury syncline by the deformed minor

* The Devonian beds are mainly those classified by the Geological Survey of Great Britain as "Lower Old Red Sandstone," but in Scotland 2,800 feet of "Downtonian" were treated as Silurian passage-beds. The Dittonian (from Ditton Prior) is 750 feet thick at Trimpley, and contains *Cephalaspis* and *Pteraspis*, as in the marine Devonian. As these Devonian mudstones contain at Trimpley no coarse detrital beds, it should be assumed that they were laid down in South Staffordshire.

† See photograph in *Brit. Assoc. Ann. Report*, 1916, page 393.

arête constituting the Barr (56C)*-Essington (6) or Bentley ridge 6½ miles long.

II.—*A Central Arête.*—The Lickey to Sedgley (19C) or "Rowley Ridge," 14½ miles long, and cut off from the Pensnett to Cradley syncline, on the south-western side of this *arête* by the Russell Hall fault, which is the septum of the fold.

III.—*The South-western Syncline*, comprising—

(*a*) The Pensnett to Cradley syncline, divided from—

(*b*) The narrow and deep Oldswinford to Kingswinford or "Swinford Basin" by the very narrow and steep "Swinford *arête*" from Hagley to Kingswinford (6 miles), with, on its south-western side, the group of faults (the Western Fault) throwing down the Thick Coal from 440 feet above sea-level at Amblecote Bank to 2,700 feet below sea-level at Stourbridge (43).†

The Thick Coal model shows that the Rowley ridge is sagged at three equidistant (4 miles) places: (*a*) near Halesowen (41B), (*b*) south-south-east of Dudley (51B), and (*c*) north-north-west of Sedgley (19C), and at these three places it is crossed by three Caledonian trend-lines. The central line connects up the anticlinal *arête* of Netherton (35-34), the synclinal ravines of Tividale (50-51), and the Walsall plateau (56B), each of these elements being 4 miles long. The north-western trend-line consists of the Himley (near 25 and 19A)-to-Sedgley Park *arête* (4 miles), beyond which it sinks into a shallow syncline (3 miles), and rises again near to and beyond Essington (6) into a narrow *arête*. The south-western one forms an *arête*, not shown on the model, from near Hagley (42A) in the direction of Halesowen (41B), which sinks into a long and broad synclinal ravine towards and far beyond Halesowen (5 miles), and then becomes a well-developed *arête* from Spon Lane (71) to beyond Great Barr (56C). The Central Caledonian trend-line, therefore, bisects each of the two Charnian synclines on the opposite sides of the Rowley ridge, that to the west-south-west being divided by a sharp *arête*, whilst that to the east-north-east is marked by narrow and deep ravines. The Central Charnian and Caledonian trend-lines form an "X."

The predominant folds in Avonian time were Charnian, as manifested by the greater length of the Rowley ridge (14½ miles) and by the floor of the coalfield.

The Pre-Carboniferous Floor.—(I) *N.E. Charnian Syncline:* (A) Cannock Chase area. At Fair Oak (2),‡ below Carboniferous beds, hard brown and Red Sandstones, with marl partings and salt water, were pierced for 46 feet 7 inches. These waters are a strong indication of Downtonian as they usually occur in those beds, as at Saltwells. I know of no instance of the presence of these waters in Dittonian. The section§ of the Cannock Chase No. 2 Pits (4), after comparing it with the Downtonian rocks mapped elsewhere, is treated thus: Carboniferous conglomerate, 17 feet; Downtonian, 837⅔ feet, with salt water (700 gallons per hour); Upper Ludlow, 65 feet as at Lye (35); and Lower Ludlow, 44 feet. At Holly Bank Pits (6) Carboniferous conglomerates rest on Downtonian, with salt waters, and their age is proved by

* All numbers next to a place-name refer to the numbers on the map (Fig. 3).

† At the Great Western Railway borehole, Stourbridge, 615 feet below sea-level, the highest Permian breccias were pierced, which at Baggeridge are 2,100 feet above the Thick Coal.

‡ *Quart. Journ. Geol. Soc.*, 1906, vol. lxii., page 523.

§ *Trans. Inst. M. E.*, 1892, vol. iii., page 50.

*Cephalaspis murchisoni and Lingula cornea.** At Haddocks Moor Pits (5) a miner who worked there told me that red Marls were pierced, and the position of this pit indicates that these marls are Downtonian. To the south-east Silurians crop out at Daw End (8A), and Jukes recorded them at Victory (9) and Ryecroft Pits (8), and in the Aldridge boring (7).

(B) *Tipton to Oldbury Charnian Syncline.*—At Chillington Pits (10) "occasional small beds of limestone and limestone clunch" were pierced about 450 feet below the Blue Flats†– practically the base of the Coal-Measures. The three Temeside bone-beds, about 100 feet above the Upper Ludlow at Saltwells‡, are small beds of limestone and limestone clunch. On this basis the Downtonian is here 550 feet thick. To the south-east at Deepfields No. 3 Pits (11) "10 beds of limestone of nearly 3 feet each"§ were pierced—evidently Upper Ludlow—upon which rested 15 feet of "clunch" and then 150 feet of "blue rocky clunch." These words describe the beds Ea just above the Upper Ludlow, and the green parts of the rocky Downtonian Sandstones and Marls *in situ* at Saltwells. The miner's "blue" is usually green. To the south-east along a line from Prince's End to Bentley the Coal-Measures at Wednesbury Oak No. 8 Pits (14) rest on limestones (probably Upper Ludlow), and at Foxyard Pits (15) on "strong blue rock 36 feet,"‖ which words describe the Sedgley Upper Ludlow limestones. The Coal-Measures rest at Pouk Hill (57) and Deepmore Pits (58) on Lower Ludlow, at Birchills (59) on 50 feet only of Lower Ludlow, and at Trentham Pits (13) and Baggotts Bridge Pits (12) on "red clunch," with salt-waters. The Lower Ludlow and lower zones pierced to the south-east will be dealt with later. At Ettingshall and Parkfield (16, 18) the Coal-Measures rest on beds a little above the Upper Ludlow, and at another pit at Parkfield (17) on Upper Ludlow.

S.W. Charnian Syncline.—It is known, since Jukes surveyed the coal-field, that the Downtonian forms the floor at the Ellowes Park outcrop (19A) (*Cephalaspis murchisoni*)¶, at Baggeridge Pits (19) (*Cephalaspis murchisoni*)¶, at Oak Farm No. 9 Pits (22), the recently reopened Deep Pits (23), and Dandy Pit Shut End (24) (thick Downtonian Marls), Old Level Pits (33), Saltwells outcrop (34), The Hayes Lye outcrop (35), Saltwells No. 24 Pit (36), and Manor Pits** (40). The specimens taken from the last-mentioned pit, in the Birmingham University Museum, are Downtonian, containing *Cephalaspis murchisoni* and *L. cornea.* At Ellowes Park outcrop and Baggeridge, Manor, and Holly Bank Pits a fish-band exists, which is the palæontological and lithological equivalent of the *Auchenaspis* band of Ledbury, and in South Staffordshire is 450 feet above the Ludlow bone-bed. It is convenient to call it "the Ledbury fish-band," so as to distinguish it from a much higher "Trimpley fish-band" I discovered there in 1917. Temeside bone-beds form the floor at Wassell Grove Pits (39) (*Lingula minima, L. cornea, and Eurypterids* I collected off the pit-bank), and the Upper Ludlow must form the floor of the Coal-Measures close to the south-west. Salt waters occur at Nos. 16,

* *Proc. Birmingham Nat. Hist. and Phil. Soc.*, 1917, vol. xiv., part 2, page 90.

† *Silurian System*, 1839, page 479, under name of "Willington;" and *Mem. Geol. Surv.*, "South Staffordshire Coalfield," 2nd ed., page 84.

‡ Cf. *Geol. Mag.*, new series, 1912, dec. v., vol. ix., pages 440 and 488.

§ *Smith's Miners' Guide*; and "South Staffordshire Coalfield," 2nd ed., pages 84 and 107; Jukes left out 15 feet of clunch.

‖ "South Staffordshire Coalfield," 2nd ed., pages 83 and 149.

¶ *Procs. Birmingham Nat. His. and Phil. Soc.*, 1917, vol. xiv., page 90.

** *Procs. Birmingham Phil. Soc.*, 1886, vol. v., page 316.

17, and 18 Shut End (25, 26, and 27).* Boot Leg (28), Honeybourne (29), and Bank (30). Red beds exist at Leys (32), and below the Coal-Measures are marls and purple and green rock at Nagersfield (31), and red marls 450 feet thick at Freehold Pits (37). All these, except perhaps (32), can be regarded as Downtonian. At Shavers End Pit (21) Coal-Measures rest on Upper Ludlow. Jukes suggested that Lower Old Red might occur at (33), and in 1866-1868 knew the Downtonian existed at (39) and (40).†

The only places in the south-western Charnian syncline where the Downtonian does not form the floor are minute areas of higher Silurians on the markedly less-denuded Caledonian anticlines of Turners Hill (near 19A), The Hayes (35), and Saltwells (34), and south-west of Wassell Grove Pits (39). Early Silurian zones should be close below the surface at Chawnhill (42), near Stourbridge.

There is a large central area where the floor is Silurian, or is of older rocks, as stated by Murchison and Jukes.‡

I.—*N.E. Charnian Syncline.* (*B*) *Tipton to Oldbury Basin and Bentley Ridge.*—To the east-south-east of the Upper Ludlow line from 15-58 this floor consists of older and older zones, so that it is Llandovery at the south-eastern end of the Bentley ridge, near Great Barr (56C). Intermediate Wenlock shales in the shallow syncline to the south-east at Titford Bridge Pits (63), and Cambrian and Uriconian in the south-eastern parts of the Rowley ridge at The Lickey. At Titford Bridge these strata were pierced 48 feet below the top of the Thick Coal.

	Ft.	Ins.	My identifications.	Ft.	Ins.
Limestone bavin	93	6	Part of Intermediate Wenlock shales ...	54	6
			Lower Wenlock limestone	39	0
Dark parting	0	1			
Bavin, with occasional bands and balls of limestone 1–4 inches thick	339	0	Lower Wenlock shales	596	1
Clear white parting	0	1			
Bavin and parting	256	11			
Total of Silurian	689	7		689	7

On the central core the Geological Survey maps show most of the pre-Carboniferous outcrops, and underground the floor is thus :—

		Feet.	
Tipton area.	Wren's Nest pits (45)	500	
	Tipton Moat No. 1 (46)§		
	,, Green (47)§		
In or near Dudley Port trough.	Coneygree No. 120 (48)	175	
	Giles (near 51)	164	Lower Ludlow.
	Dudley Port No. 2 (50)	102	
	Bagnalls (51)§	69	
	Castle Foot (52)		
Near Walsall plateau.	Hobbs Hole (53)‖	60	
	Patent Shaft & Axle Co. (54) ...		Lower Wenlock limestone.
	Hateley Heath (55)		
	Friars Park Wood (56)		Lower Wenlock shales.

* Cf. "South Staffordshire Coalfield," 2nd ed., page 82.

† *Geol. Mag.*, new series, 1912, dec. v., vol. ix., pages 438 and 439.

‡ *Silurian System*, 1839, pages 464 and 491 ; and "South Staffordshire Coalfield, 2nd ed., pages 81 and 110 and preface.

§ "South Staffordshire Coalfield," 2nd ed., pages 83-84. ‖ *Ibid.*, page 161.

Oldbury district.	Old Blackheath (60) *	Homogeneous Silurian shales, 340 feet thick, and so Lower Wenlock shales.
	Cakemore (61)	Silurians (zone unknown), probably Lower Wenlock limestones.
	Nine Apostles (62)	
	Coppice, Langley Mill (64) † ...	Silurian shale, which the structure shows are Lower Wenlock shales, about 100 feet below the Lower Wenlock limestone.
Spon Lane syncline.	Moat Farm boring (65)	Lower Wenlock shales (*Phacops musheni*). Mr. Bloomer has it.
	Blakeley Hall (66)	Silurian shales.
	Lewisham (67) ‡	
	Lyndon (68) ‡	Silurian.
	South Staffs. Colliery No. 1 (69) ...	Silurian in east workings (Mr. Davis).
Spon Lane ridge.	Heath West Bromwich (70)	180 feet of Wenlock shales, with Barr limestone (*Illænus barriensis*) below. Found by Mr. Johnson.
	In gate-roads east of Spon Lane and west of Sandwell (71)	Silurian shale, with limestone bands (*Nucleospira pisum* and *Rhynchonella lewisii*). Given to me by Mr. I. Meachem.
	Sandwell gate-roads under Park Lane near Handsworth and East Lodge of the Park (72)	Red Measures, with bavin (Silurian) below, were seen by Mr. F. G. Meachem, and marked on his plans.
	Jubilee, Sandwell (73)	Silurian and, below, Cambrian quartzite.

(II).—*The Rowley Ridge.*—Along this ridge to the north-north-west at Sedgley (19C) the floor consists of Downtonian and Upper Ludlow, further south-south-east at Dudley (51C) of Lower Ludlow and Wenlock limestones and shales; at Dixon's Green (51B), after crossing a downthrow to the south-south-east, of Lower Ludlow 100 feet thick; at Springfield (74) of Silurian; at Knowle Pits (75) of 11 feet of Lower Ludlow; at Pennant Hill Pits (76) of Upper Wenlock limestone; at Yew Tree Pits (78) of Intermediate Wenlock Shales (in a gate-road driven on to the Rowley Ridge); at Old Blackheath Pits (60) of Lower Wenlock shales; and at The Lickey, to the south-south-east, of Woolhope limestones and shales, Llandovery sandstones, Cambrian quartzite, quartzose-grits, and Uriconian.

The map (Fig. 3) shows the pre-Carboniferous floor of the coalfield.

The foregoing is summarized thus:—

In Avonian time there was a central core, 14½ miles, or more, long from south-east to north-west, Lickey to Sedgley (19C), and 9 miles wide from the north-north-east to south-south-west, Walsall (56B) to Coombes Wood (41A), which had been above the base level of denudation for so long that the pre-Carboniferous rocks had been swept off it down to either the Silurian or older rocks as far as the Uriconian.§ This central core lies to the south-east of a Caledonian strike-line through Prince's End to beyond Daw End (15-8A), and is bounded on its south-western side by the master *arête* of the Rowley ridge, with the oldest rocks bared at Lickey,

* "South Staffordshire Coalfield," 2nd ed., 1858, page 81.

† *Ibid.*, page 177.

‡ *Ibid.*, page 138.

§ The Basal Coal Measure conglomerates contain very rare Uriconian fragments and vast quantities of Cambrian quartzites.

and Great Barr (56C) at the south-eastern parts of the two Charnian ridges of Rowley and Bentley. Outside this central core, in both the north-eastern and south-western Charnian synclines and the area at Deepfields (11) and Ellowes Park (19A) connecting these two synclines, the floor of the Coal-Measures is almost exclusively Downtonian. At Chillington Pits (10) to the north-north-west, 2,250 feet of the Devonian, and at the north end of Lickey to the south-south-east 4,700 feet of Devonian and Silurian, were denuded in pre-Middle Coal-Measure time; and farther to the south-south-east, at Barnt Green Lickey, an unknown thickness of Cambrian.

The Avonian and Post-Avonian Charnian Movements.—The intensity of these early Charnian movements can be gauged by taking a section from the north-east to south-west through these places. At Coppice Pits (64) the floor is composed of Lower Wenlock shales; at Titford Bridge Pits (63) of Intermediate Wenlock shales 93½ feet above the base of the Lower Wenlock limestone; at Old Blackheath Pits (60) of a zone not higher than the base of that limestone; and on the crest of the Rowley ridge at Coombes Wood (41A) of Lower Wenlock shales at least 50 feet below the Lower Wenlock limestone. The Golden Orchard Pits (41) are 3 miles from the Saltwells outcrop (34) and 1 mile from Manor Pits (40). At the former 135 feet of Downtonian are left, and at the latter 450 feet, including the Ledbury fish-band, and on this basis 370 feet remain at Golden Orchard. Therefore, at Coombes Wood 1,135 feet of Downtonian and Silurian are missing that are intact at the Golden Orchard Pits.

The Coal-Measures below the top of the Thick Coal are 48 feet thick at (63) Titford Bridge; at (60) Old Blackheath, in a sag before the final rise to (41A) Coombes Wood, 96 feet thick, and probably at (41A) very thin (say 35 feet); whilst at (40) Manor Pits they are 281 feet, and at (41) Golden Orchard at least 200 feet thick.

The top of the Rowley *arête* at Coombes Wood (41A) was denuded until a cliff, about 165 feet high, was left by the Golden Orchard Pits (41) in pre-Middle Coal-Measure time. The lowest Middle Coal-Measures filled up the syncline to the top of the cliff, *and then 35 feet of Coal-Measures up to and including the Thick Coal were with higher beds laid down on one plane across these old dislocations.* The minimum throw to the south-west of the Russell Hall faults *at this place* in pre-Middle Coal-Measure time was (1,135 + 165 =) 1,300 feet.

The Thick Coal is thrown down 826 feet between (41A) and (41) entirely by the cumulative effect of all the subsequent movements, which reformed the Rowley ridge and further fractured this old and deep-seated line of weakness.

Two miles to the north-north-west at Knowle Pits (75) the pre-Middle Coal-Measure movements caused dislocations amounting to at least 805 feet, for these beds, intact in the syncline, are missing on the arch (Downtonian 250 feet, Upper Ludlow 65 feet, and Lower Ludlow 490 feet); whilst the subsequent movements have thrown down the Thick Coal only 268 feet between The Knowle (75) and Bourne Hill Pits (77). Farther to the north-west the throw of this fault continues to diminish rapidly.

The fractures produced along the Russell Hall fault-line, by movements in Avonian and perhaps earlier times, far exceeded those caused by all the subsequent movements up to to-day. A group of faults of such magnitude are but very slowly formed. It follows also that the faults which divide the parallel Swinford ridge from the deep Swinford basin had analogous origins.

The Avonian and Post-Avonian Caledonian Movements.—In the north-eastern Charnian syncline the strike of the pre-Carboniferous floor in Avonian time was apparently Caledonian for 11 miles; and the Rowley ridge was in pre-Coal-Measure time sagged by the three Caledonian trend-lines.

Fig. 1.—Photograph of the Hayes Lye (1913), showing Coal-Measures resting on Denuded Downtonian.

The instructive section (Fig. 1) at the Hayes (35) was photographed by Mr. H. Evers-Swindell, and Fig. 2 is a tracing from the photograph. We marked with chalk, and my hand is seen on the upper part of the boundary

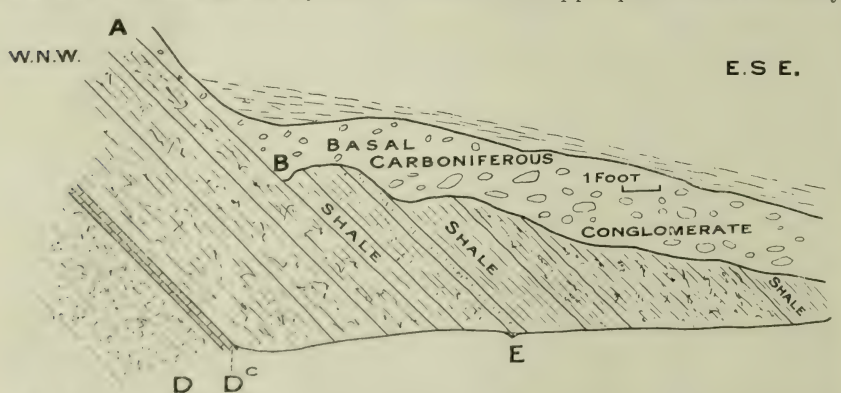


Fig. 2.—Section at Hayes Lye, showing Coal-Measures resting on Denuded Downtonian (Drawing from the Photograph, Fig. 1).

between the Coal-Measures and the pre-Carboniferous. A quartzite pebble and some of the bedding planes are similarly marked. The long slope *A B* (Fig. 2) is composed of the Downtonian overlying the Ludlow bone-bed (*Dc*), and to the east are denuded ribs of Downtonian Sandstones (*E*), with hollows in the softer bands. The basal Coal-Measures—including a quartzite pebble $3 \times 1\frac{1}{2} \times 1\frac{1}{2}$ feet—fill up the hollows, overstep the basset

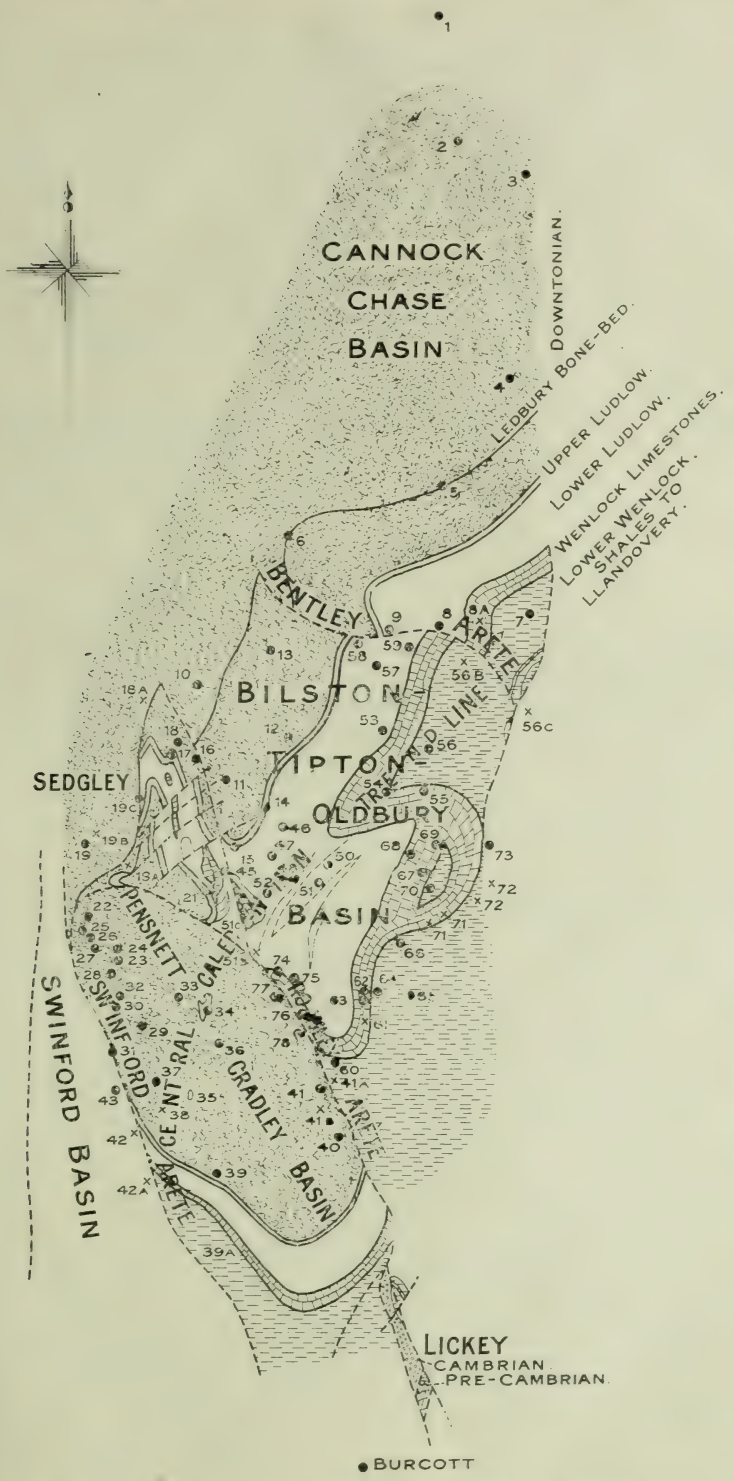


FIG. 3.—MAP OF THE PRE-CARBONIFEROUS FLOOR OF THE SOUTH STAFFORDSHIRE COALFIELD. SCALE, 4 MILES TO 1 INCH.

edges of the Downtonian, and creep up and are laid down against the cliff. This ridge existed in pre-Middle Coal-Measure time. This section gives in miniature what has happened on a larger scale in the Dudley-Sedgley area (51C-19C), as mapped there by me. When, however, in South Staffordshire these Caledonian ridges are compared with the Charnian *arêtes*, the latter are found to be much greater in length, breadth, and height. For instance, the Charnian central *arête* is 14½ miles long as against the Caledonian central ridge, which is 4 miles long; and the Silurian in Avonian time was exposed on the Charnian anticlines for many square miles, as against less than one-quarter of a square mile on the Caledonian anticlines. In Avonian time the rocks exposed on the Charnian ridges were the more deeply-seated zones, especially at their south-south-eastern ends. These Charnian ridges were barriers which obstructed the later movements, whilst the less elevated contemporaneous Caledonian ridges were composed largely of the Downtonian mudstones, which yielded more readily. Furthermore, the north-north-western ends of the Charnian ridges, composed of Lower and Upper Ludlow, were also more tractable. The movements along the Caledonian trends in Avonian and post-Avonian times can be contrasted where the three sags in the Rowley ridge exist.

(*A*) *Halesowen Sag* (near 41B).—There is no information available in the sag, but the line of fault from Cakemore to Langley (61-64) appears to be a continuation. Here on the upcast side are the Coppice Pits (64) and on the downcast side the Moat Farm boring (65). The floor at (64) is composed of Lower Wenlock shales 100 feet below Lower Wenlock limestone, and at (65) Lower Wenlock shales (zone unknown). As those shales are 600 feet thick, the pre-Coal-Measure dislocation cannot be more than 500 feet. The Thick Coal is 280 feet above sea-level at (64), and Mr. Bloomer is of opinion that it was pierced 816 feet below sea-level at (65), a difference of 1,096 feet due to later movements.

(*B*) *The Dixon's Green Sag* (51B).—Dudley Castle (51C) is on the junction of the Lower Wenlock limestone and the Lower Wenlock shales, and is 737 feet above sea-level. At Dixon's Green (51B) 100 feet of Lower Ludlow shales remain, and so there these beds are intact that are missing at (51C), namely: Lower Ludlow, 100 feet; Upper Wenlock limestone, 16 feet; intermediate Wenlock shales, 100 feet; Lower Wenlock limestone, 36 feet; or a difference of 252 feet, which represents as near as can be estimated the pre-Coal-Measure dislocation here. The top of the Thick Coal at the Prince of Wales Pits (51B) is 230 feet above sea-level, at Knowle Pits (75) it is thence 164 feet to the Upper Wenlock limestone; and so at (51B) the top of the Lower Wenlock shales should be 165 feet below sea-level, as against 737 feet above sea-level at Dudley Castle, or a difference of 902 feet, due mainly to post-Thick Coal movements.

Somewhat the same result, as to the earlier dislocation, is arrived at thus. At (63) Titford Bridge 1,174 feet of pre-Carboniferous rocks are missing that are intact at (10) Chillington. The dip is 1 in 31½. This, however, ignores the Caledonian folding. On the upcast side of the Dudley Port trough is Coneygree No. 120 Pit (48), and 4½ miles to the north-west is Chillington Pit (10). At (48) 940 feet of strata are missing that are intact at (10), which gives a dip of 1 in 25 $\frac{3}{7}$. Taking 940 feet × 25 $\frac{3}{7}$ ÷ 31½, the result is 754 feet, which indicates that at Dudley Port (50-51) there was a pre-Coal-Measure dislocation of 186 feet. There are post Thick Coal dislocations at Dudley Port of 420 feet or less.

(*C*) *The Himley* (near 25) *to Sedgley* (19C) *Sag*. The Western Faults exist here. Situated on the upcast side of these faults is Ellowes Park

(19A), and on the downcast side Baggeridge Colliery (19). On both sides the Downtonian forms the floor with the Ledbury fish-band below. The Coal-Measures rest at (19A) on Downtonian marls 25½ feet above the fish-band, at Wood Farm gate-road (19B) on marls of the same age 52 feet above that band, and at (19) they pierced 134 feet of the same marls without apparently reaching that band. The top of the Thick Coal at Ellowes Park, if restored, would be 600 feet above sea-level, and in Baggeridge shaft is 1,198 feet below sea-level. The pre-Coal-Measure declivity was over 110 feet, and the cumulative effect of all the later movements has produced downthrows of the Thick Coal (laid down on one plane) of 1,800 feet, or more, according to the points between which it is taken. This gives the following results:—

	Pre-Coal-Measure dislocations. Feet.	Post Thick Coal dislocations Feet.
To north-east of Halesowen sag at 64	500 or under	1,096
,, Dixon's Green sag (51 B)	250	900
,, Dudley Port trough (51)	186	420
,, Himley sag (19 A)	over 110	1,800

The movements along Caledonian trends were in Avonian time greatest to the south-east, whilst in post-Avonian times they were greatest to the north-west, and everywhere exceeded the earlier movements along these trend-lines.

In Avonian time the dominant anticlines, synclines, and faults *in South Staffordshire* were Charnian, and the highest crests of the ridges lay to the south-east, and there was then a weaker creep *in this district* along Caledonian trends, which increased in strength, especially in Coal-Measure time, to the extent that, as shown by Jukes, the dominant strike of the Coal-Measures is Caledonian.

The Area of Deposition of the Avonian.—The time of these earlier Charnian and Caledonian movements can be fixed stratigraphically to some extent.

In Devonian time there was no marked movement in South Staffordshire, for in that coalfield and at Trimpley the Downtonian is essentially composed of mudstones, and at Trimpley the Dittonian contains coarse sandstones, with rare and very small pebbles. The rare conglomerates in the Downtonian that do occur in certain parts of the Shropshire Devonian are very fine conglomeritic sandstones. The first coarse conglomerate is in the overlying true Old Red (Upper) of the Forest of Dean and South Wales, which rests unconformably on the beds below and contains fishes of quite different types: and on these grounds important movements at that time have been inferred by many writers.

At Fair Oak (2) in the deeper parts of the north-eastern Charnian syncline, Avonian grits and limestones of D^{2-3} have been proved in a gate-road, and, presumably, Downtonian in the boring below. On the pit-mound I found large pieces of conglomerate containing *inter alia* many fossiliferous Avonian pebbles from 2 to 3½ inches long. In the published section there are two grits, 182 and 264 feet respectively above the Downtonian, one or both of which may represent one or more of those Basal Coal-Measure conglomerates which so frequently occur in all the synclines of South Staffordshire. Below the highest grit several rocks were pierced, the descriptions of which tally with pieces I found on the mound containing Avonian fossils. In my opinion, based on three visits, the highest Avonians were pierced in the shaft for 264 feet.

The Avonian was also laid down to the south, near Holly Bank Pits (6), for the two Basal Coal-Measure conglomerates there contain many large (up to $18 \times 10 \times 11$ inches) and some sub-angular Carboniferous

fragments, of which no less than 86 per cent. are Carboniferous ironstones and grits and Avonian sandy and dolomitic limestones, the latter largely predominating; 13·2 per cent. are Silurian 1 to 3-inch pebbles, and 0·8 per cent. are Cambrian quartzites 1 inch long; thus indicating, inasmuch as the Silurians and Cambrians were then exposed to the south-east, that the Carboniferous detritus has been derived from sources to the south-east. Mr. J. C. Forrest most kindly brought up about 300 pebbles, of which 121 have been examined, and the percentages have been based on them.

Probably the Avonian was also pierced at Cannock Chase Pits No. 2 (4), to the north-east of Holly Bank, between the band 3 feet thick described as "Breccia containing pieces of limestone" and the conglomerate 17 feet thick which rests on the Downtonian. The beds referred to are 227 feet 1½ inches thick as against 264 feet at Fair Oak.

In the south-western Charnian syncline, in the south-eastern parts at Wollescote (38), the Basal Coal-Measure conglomerates contain 30 per cent. of Silurian limestones, Llandovery sandstones, Cambrian quartzites, and quartzose grits, and extremely rare Uriconian rock-fragments—similar to the same rocks *in situ* at The Lickey—and 70 per cent. of Carboniferous detritus; whilst close by, on the Saltwells Caledonian *arête* (35-34), these conglomerates contain not more than 10 per cent. of small pebbles of Carboniferous age, and the rest are the same pre-Carboniferous rocks as found in the Wollescote conglomerates.

The Carboniferous detritus at Wollescote (38) includes sub-angular pebbles of sandy limestones, and one contains an Avonian fossil, identified by Mr. Newton as "a postulose structure closely related to *Productus pustulosus.*" Embedded in a band of mottled clays, between two of these basal conglomerates, are an enormous number of unworn blocks and slabs of pink calcareous grits and *calcareous breccias containing small pieces of limestone.* Some of these slabs are from 2½ to 3 feet thick and 6 feet long, and may possibly be comparable with the breccias containing pieces of limestones pierced at Cannock Chase Pits No. 2. Their immense size, irregular shapes, unworn edges, partial resemblance to the lowest Carboniferous conglomeritic grits *in situ* at Wollescote, their extraordinary abundance in the syncline there, and their absence as slabs and blocks from the basal conglomerates on the Saltwells *arête*, point to disintegration *in situ.*

The contents of the so-called Permian conglomerates also indicate that the highest Avonians were laid down close by. It has been ascertained that (excluding the Carboniferous fragments) their constituent materials vary from area to area, so that each one agrees with the rock succession *in situ* that was exposed in these times in the specific part of the Mercian Highlands to the south-east or east which was nearest to each particular area.* They are locally derived, and furthermore each particular area had its own peculiar sub-local source. The inference was made that as the source of all the pre-Carboniferous fragments lay to the south-east or east, and the materials were markedly coarsest in those directions, therefore the Carboniferous fragments come from the same directions.

The so-called Permian conglomerates† contain the following percent-

* *Quart. Journ. Geol. Soc.*, 1899, vol. lv., pages 123-127, with map; and *Proc. Geol. Assoc.* 1898, vol. xv., pages 376 and 377.

† Dr. W. Gibson recognizes the difficulty of ascertaining whether these are Upper Coal Measures or Permian. I agree that their age is not settled. In the overlying Permian breccias I found in 1914 casts of fern-like petioles. Consult *Coal in Great Britain*, pages 206, 212, and 216; and Arber, *Trans. Inst. M. E.*, 1916, vol. lii., pages 39-42; and Mr. Hardaker, *Quart. Journ. Geol. Soc.*, 1912, vol. lxviii., page 639.

ages of pebbles of Avonian dolomitic and non-dolomitic limestones and Carboniferous grits in the areas marked (1) nearest to the south-western, and in the area marked (2) nearest to the north-eastern Charnian synclines :—

	Area.	Miles N. or N.E. of Abberley	Percentage.
(1)	Warshill	5½– 6½	20
	Bowhills	8 –11½	20-25
	Enville	10½-14½	30-40
	Stourbridge (43) to Baggeridge (19)	13 –17¾	60
(2)	Warley (65) to Barr (56 C)		60

Dr. Vaughan wrote to me provisionally identifying these. "A chert very likely radiolarian"—"*Michelinia tenuisepta* cf D^{2-3}," "*Chonetes*, sp ? (looks like a D^{2-3} species)." "*Syringopora* of D^{2-3} or Pendleside type," "*Caninia* of *cornucopiæ*." "They seem to me most likely to belong to the Pendleside level ($D\gamma$) or thereabouts." No sections of them have been made. Three came from Bowhills. Whilst, on the one hand, the areas of so-called Permian conglomerates laid down nearest to the previously denuded Lickey ridges are nearly entirely trappoid conglomerates, yet, on the other hand, the areas of Warley-Barr (65 and 56C) nearest to the north-eastern Charnian syncline existing in late Avonian time, and the areas of Warshill, Bowhills, Enville, and Baggeridge nearest to the deepest parts of the corresponding south-western Charnian syncline, are largely composed of fragments from the highest Avonian, and these conglomerates are coarsest to the south-east or south, and pass, outwards, to the north-west or north into sandstones. These Avonian fragments abound in the Baggeridge area (19) to the north, and diminish in quantity in the Warshill-Bowhills area to the south as if they thinned out to the south-east. In this respect the South Staffordshire south-western syncline would agree with the parallel long south-western syncline of Charnwood, where it is known that the Avonian is only 20 feet thick in its south-eastern parts near Desford, and increases in thickness to the north-west.

The Distances the Pebbles in the Carboniferous Conglomerates travelled.—Although it is difficult to ascertain how far these north-eastern and south-western Charnian synclines of South Staffordshire extended to the south-east, still there are indications, founded on similar conglomerates in Persia and on the transition of the thick conglomerates in and near South Staffordshire to sandstones, which prove the distances the coarser materials have travelled. Dr. Blanford has shown* that in Persia hill-ranges exist with valleys in between, sometimes in length 30 miles, and in width 20 miles, diminishing to 10, and that it is a country which has undergone a transition from a humid climate which became increasingly arid. He describes great slopes of gravel and boulders mixed with sand, extending from the hills there for 5 to 10 miles, with fragments 2 to 3 feet in diameter a mile or two from the base of the hill-ranges, where small streams issue. The innermost and more elevated parts of the valleys are occupied by loose detritus (breccias), with the higher peaks and ranges rising out of them, particularly in the most arid tracts. He thinks the gravels were chiefly accumulated in "enclosed basins" constituting large lakes, when the climate was not so arid.

The conglomerates associated with the Coal-Measures in South

* *Quart. Journ. Geol. Soc.*, 1873, vol. xxix., page 493.

Staffordshire can be grouped as (1) the Basal (Middle Coal-Measure) conglomerates, at Wollescote (38) at or within 70 feet of the floor; (2) the Espley Coal-Measure conglomerates, in the Cradley area from 56 to 857 feet above the Thick Coal; and (3) the so-called Permian conglomerates, proved by gate-road levels in the Baggeridge area (19) to be 1,580 to 1,880 feet above the Thick Coal there.

(1) In the north-eastern Charnian syncline the Basal conglomerates of Holly Bank (6) contain only 13·2 of Silurian and 0·8 per cent. of Cambrian fragments, and, in those times, the former were exposed *in situ* 5½ to 15½ miles to the south at Sedgley-Lickey, and the latter 15½ to 18 miles to the south at Lickey. The largest of these fragments found is a 3-inch well-rounded pebble. As the Silurian was exposed nearer *in situ*, its *débris* is more abundant, whilst the quartzites pebbles—only 1 inch long—apparently mark the extreme length of the drift from The Lickey, 18 miles, but may possibly have come from the Great Barr (56C) direction 7 to 8 miles.

In the south-western Charnian syncline the Basal conglomerates crop out within 2 to 6½ miles west-north-west and north-west of the old ridges at The Lickey, and consist of several thick and coarse bands of pebbles—pebbles up to $3 \times 1\frac{1}{2} \times 1\frac{1}{2}$ feet exist, and some are sub-angular. To the north-west at Ellowes Park outcrop (19A) they have become one band of coarse sandstone 10 *miles from The Lickey*. The pre-Carboniferous fragments in these Basal conglomerates of this syncline are almost exclusively the Cambrian and Silurian rocks *in situ* at The Lickey. The pre-Cambrian area bared then on the parent ridges was extremely small.

(2) The Espley conglomerates exposed in the Cradley basin are within 3 to 5 miles of The Lickey, and contain a wider range of fragments similar to rocks *in situ* at The Lickey and Nuneaton. The pre-Cambrian fragments progressively increase vertically in quantity, especially in the higher bands. At Baggeridge Pit (19), 11 miles north-west of The Lickey, only four of these conglomerates are shown in the shaft section, thus :—

	Height above Thick Coal. Feet.	Thickness. Feet
Blue conglomerate rock	670–685¼	15¼
Conglomerate rock	463–467	4
Hard grey rough sandstones, with flint pebbles ...	420–424	4
2-foot conglomerate, with large pebbles; 9-foot grey sandstone, and large pebbles of all colours	375–386	11
		34¼

To the south-east at the Manor Pits (40), 3 miles north of The Lickey, fourteen bands of Espley conglomerates of an aggregate thickness of 134 feet were sunk through, and range from 70 to 857 feet above the Thick Coal. These two pits are 8 miles apart, and so the loss in thickness is 12 feet per mile, and, continued at the same rate to the north-west, these conglomerates should *cease to exist* 14 *to* 15 *miles from The Lickey*.

(3) The so-called Permian conglomerates of Enville and of Warshill-Bowhills are coarsest and thickest to the south-south-east, and in 4 miles north-north-west of Enville and 6 miles north-north-west of Warshill they become sandstones. The Warley-Barr conglomerates are thick and coarse to the south at Warley (65), and thinner and finer at Barr (56C) 6 miles to the north. The Clent Hills (39A) conglomerates extend to, at any rate, Goldthorn Hill (18A), 14 miles from Beacon Hill, Lickey.

The materials in the Basal and Espley conglomerates that occur within 5 miles of The Lickey, and in the Warley conglomerates (by 65), are coarser than those at Enville, Warshill, and Bowhills, indicating

that the latter are farther from their source. The Bowhills conglomerates become sandstones at Coton. The conglomerates should be, and are, as a rule, farther away from the old ridges than the coarse breccias. At Burcot, near Bromsgrove, 17 miles south-east of Coton, a borehole was made close to the ancient Lickey *arête*, and I saw the cores, the lower parts of which were of coarse and thick Permian breccias of such a character that the parent rocks should be quite close. They resembled the coarse and thick breccias of Walton Hill.

The conglomerates associated with the Coal-Measures become sandstones within 10 to 16 miles of the parent ridges—the Basal conglomerates thus changing in 10 miles. Upon this basis, the deepest parts of the south-western Charnian syncline might receive deposits of $D^{2-3}\gamma$ to about a line from Abberley to Droitwich, the latter place being 21 miles south-east of the north-north-western end of the Rowley ridge and 16 miles from Coton. Geologists who think that these pebbles have travelled longer distances from the parent ridges will presumably assign these Avonian pebbles—clearly derived from the south-east—to more remote sources.

The Plexography in Avonian Times.—Murchison's and Jukes' views that the Carboniferous Limestone and Millstone Grits were not laid down in or near South Staffordshire are correct if the deeper parts of the large north-eastern and south-western Charnian synclines are entirely excluded. A central Charnian arch existed in South Staffordshire in Avonian times, with large and long synclines to the north-east and south-west of this arch. The synclines were wider than the anticlines. There were corresponding Charnian crests at Caldecote in Warwickshire and Charnwood in Leicestershire, with corresponding long Charnian synclines, in one of which Avonian beds are known to exist as far, at any rate, as Desford. In South Staffordshire, in the deeper parts of the north-eastern Charnian syncline, Avonians $D^{2-3}\gamma$ were deposited, and are intact, and extended over much of the Cannock Chase parts of that syncline; whilst in the deeper parts of the corresponding south-western Charnian syncline the same beds were laid down and disintegrated *in situ* at Wollescote (38), and the structure points to their presence *in situ* in the still deeper Swinford basin. The derivation of the so-called Permian conglomerates—clearly derived from the south-east—shows that they were laid down far to the south-east, probably to Droitwich. Vaughan's *Upper Visean* shore-line should be continued with a main Caledonian trend, from near Droitwich to and beyond Charnwood, very deeply indented by long Charnian anticlines and synclines, athwart the main direction, and with the Malvern and Abberley range (north and south) forming the central axis of this curving shore-line extending from Anglesey to the Humber. The Avonian denudation planed down the anticlines within the South Midland Coalfields.

The Post-Avonian Folding: The Armorican Faults.—In the northern and southern compartments of the "X," formed by the Central Charnian and Caledonian trend-lines of South Staffordshire, Armorican faults prevail in the Thick Coal, and it is almost a universal rule that these faults throw towards the centre of the "X." They never broke through the south-eastern parts of the Charnian *arêtes* where the deeper-seated rocks had been raised; yet they did succeed in fracturing the more tractable rocks at the north-north-western end of the central Rowley ridge (11-19A) and the south-south-western part of the Central Caledonian *arête* at (35). These east-and-west faults join up with Caledonian faults, with diminished throws, that pass through the north-north-

western end of the Rowley *arête* (between 11 and 19A), and the latter form large faults across the more tractable rocks of the Pensnett basin. It is evident that this later creep operated along the lines of least resistance.

The Malvernian Folds.—The denudation of the Avonian zones laid down in the south-western and north-eastern Charnian synclines of South Staffordshire involves that they were first ridged up. One of these ridges was in the Stour Valley between the Clent Hills and Trimpley on the western side of that coalfield, and the other in a corresponding position—perhaps the Blythe Valley—on the western side of the Warwickshire Coalfield.

With reference to the Stour ridge, there is on its eastern side a transition from the south-south-east to the north-north-west in the constituent fragments in the *Permian* breccias of the adjacent Clent Hills (39A-42), consisting of Walton Hill to the south-south-east, then Clent Hill and Wychbury Hill, and to the north-north-west Chawn Hill (42). The fragments at Walton Hill are almost exclusively pre-Cambrian of varied types, at Clent Hill in the lower layers they are the same, but in the upper layers there are large quantities of most angular Llandovery sandstones*; at Wychbury Hill a few pieces of Woolhope limestone first appear; and at Chawn Hill, in the reservoir made there, very angular Wenlock limestones and Llandovery sandstones were abundant. This arrangement is consistent with a closely adjacent ridge, only partly denuded in the so-called "Permian" conglomerate period, very probably raised further, and the nose of which was tapering off to the north: so that in that direction the breccias progressively comprise younger *débris* from the lower parts of this ridge, whilst its higher and more denuded parts and the older denuded ridges nearer The Lickey afforded vast quantities of *débris* from deeper-seated zones. On the western side of the Stour ridge the upper layers of the Enville breccias contain many Llandovery fragments, and the Warshill breccias 4 miles to the south are almost exclusively Archæan *débris*.

The Stour ridge should obstruct the movements in operation after its creation. The Charnian synclines shown on the model of the Thick Coal consist to the north-east of the wide and relatively shallow Tipton-to-Oldbury syncline, to the south-west of the narrower and deeper Pensnett-to-Cradley syncline, and farther to the south-west of the narrow and deep Swinford abyss compressed against the Stour ridge. Furthermore, on the eastern side of the coalfield that model depicts the results of the pressure from easterly directions, where sharp and complicated folds exist between Spon Lane (71), Langley (64), and Blackheath (60), composed of the homogeneous and tractable Lower Wenlock shales that had been left there after the Avonian denudation.

To the west of the Lower Severn and Stour Valleys it is well known that, along the Malvern and Abberley Hills, the rocks have been thrust from the east. Mr. Cantrill has shown that at Trimpley there is an overfold to the west, due also to the same cause, and I have ascertained that at Trimpley the rocks involved in this folding include Keele Beds. It was owing to this eastern pressure, operating on the Warwickshire and South Staffordshire anticlines, that their south-western Charnian synclines, composed of more tractable rocks, were ridged up. If, as is probable, this pressure was powerful enough to produce thrust-planes in the so-called "Permian" conglomerate period, it would account for

* Cf. *Mid. Nat.*, 1893, vol. xvi., page 6.

the Haffield (Permian?) breccias of Abberley and Woodbury Hills being subsequently laid down across marked thrust-planes that I have mapped there. That the breccias at and south of Warshill, Stagbury, and Abberley rest unconformably on all the rocks below has been recognized for many years.

It has been my object to make some return to the mining community of South Staffordshire for their generous help by producing results of utility to the coal industry.

It is well known that in the vicinity of the Charnian ridges near The Lickey the Coal-Measures deteriorate greatly, whilst to the north and north-west are the rich Cannock Chase coals and ironstones.

Coals must be found at reasonable depths if capital and working expenses are to be kept down, and it is in this connexion that the Malvernian ridges, created* after the coals were laid down in the Stour Valley and at or about the Blythe Valley, are of such vast importance. To prospect for coals south of an east-to-west line through Stourbridge (43) is foredoomed, unless the speculation is confined to the parts constituting the complicated troughs on each side of the Stour ridge, as south of this line denudation has removed the coals off this ridge. If a shaft were put down further north, between Kingswinford (near 27) and Enville, away from the troughs on each side of the Stour ridge, of which the deep Swinford basin is one, then it may be presumed that, on the ridge, only parts of the pre-Triassic measures have been denuded. Friends of mine who knew Jukes told me that he advocated a sinking on Highgate Common near Enville, and this is probably the reason why this boring was made there in 1857-1858, of which the following is a summary:—

		Ft.	Ins.
	Lower Bunter Sandstone	275	6
	So-called "Permian" conglomerates: Pebbly rock or conglomerate	8	0
	So-called "Permian" conglomerates: Red rock and marl	13	0
	So-called "Permian" conglomerates: Very hard red rock and sand-grit	14	6
Keele.	Red sandstones and marls, 15 feet of hard red sandstone, variegated blue and red rock, and blue and mottled ground, etc.	182	0
Keele.	Light rock	1	0
Keele.	Red rock, brown sandstones, and light gritty rock, marls, etc., and 10 inches of strong blue rock at base...	41	10
Keele.	Very hard light stone		6
Keele.	Strong marl, and red rock marl	8	2
Keele.	Very hard blue, and mottled rock	2	6
Keele.	Variegated rock...	14	4
	Total	561	4

Here Permian breccias and conglomerates 500 feet thick have vanished. At Baggeridge it is 1,580 feet from the base of the so-called Permian conglomerates to the Thick Coal. The Smestow boring, where a good bright hard coal was found, was in the trough.

As the length of the drift of the coarser materials in the Permian breccias and Carboniferous conglomerates can be ascertained, they are indices to where the coals exist and their quality. These conglomerates become sandstones in 10 to 16 miles, and the breccias become marls, with thin breccia sandstones—as at Sedgley Hall Farm (between

* I adopt Prof. Lapworths' view that the Malvern range existed in the greater part of Carboniferous times; but in later Carboniferous times the ridges were extended northward, and this is the creation referred to.

19B and 19C) and Gatacre—in from 5 to 8 miles from the parent ridges. At Baggeridge (19) the Thick Coal is intact and good, the Basal conglomerates are sandstones, the so-called Permian conglomerates are rather fine and are passing into sandstones, and the Permian breccias are nearly entirely marls. Therefore there was no danger of the coals here being rubbish or absent, as the coarser detritus from the Charnian ridges then being denuded was not carried to that place, and the more deeply denuded parts of the Stour ridge must be from 5 to 8 miles to the south.

In those localities where these detrital deposits are coarse—as near Clent Hills (39A)—a boring for coal will be a failure, as the old Charnian and denuded Malvernian ridges are close by. The absence of any workable coals at Wassell Grove Pit (39) is an instance of coals laid down close to Charnian ridges then being denuded. If the boring is made north of Wolverhampton (18A), rich and less fractured seams will be found, but the greater depth and water difficulties may make progress slow; whilst in the old Charnian syncline to the south, provided that the boring is not made too close to the coarser areas of Permian breccias and of so-called "Permian" conglomerates, coals of good quality, but more faulted, will be found at increasingly less depths; and it necessarily follows that there are places in both the Stour and Blythe Valleys where the Trias rests directly on the productive Coal-Measures, as at Cannock Chase.

The President (Mr. J. R. Felton): I think that we should all prefer, if Mr. Wickham King agrees, to postpone the discussion upon the paper until we have had time to digest it, when we hope that the author will be present to give us any further explanation that may be necessary.

Mr. W. F. Clark (Aldridge): I agree with the President that the subject is too great for us to grasp without further consideration. Mr. King has given us the results of a lifelong work, for he has studied the South Staffordshire Coalfield probably more than any other man in England. If, instead of recording all these results in one paper, Mr. King had been kind enough to give them in three, I think we should have been able to assimilate them more easily.

I should like to mention that in my own experience Mr. King has on several occasions prophesied certain depths at which we should find certain coals, and I have never known him to be wrong. I think that is the greatest compliment one can pay to the author, because Mr. King has reasoned by deduction from a comparison of levels, and so on.

Mr. W. Wickham King (Stourbridge): Some years ago I remarked that I thought mining engineers were not sufficiently helpful to geologists. I withdraw every word I then said. The measure of help I have received from the mining community of South Staffordshire has been astonishing to me. They have all assisted and given me many hours of valuable time. I am afraid that this paper, which took me two months to prepare, notwithstanding all the previous study I had given to the subject, cannot be conveniently discussed at this sitting. Perhaps, as Mr. Clark states, the matter is too much to put into one paper. I am glad that you have found it interesting, and I hope that you will also find in it the material for a profitable discussion.

THE NORTH STAFFORDSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING,

HELD AT THE CENTRAL SCHOOL OF SCIENCE AND TECHNOLOGY, STOKE-ON-TRENT, JULY 25TH, 1921.

MR. J. R. L. ALLOTT, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been previously nominated, were elected :—

MEMBER—

MR. JOHN COCKS, Shelton Iron, Steel, & Coal Company, Limited, Stoke-on-Trent.

ASSOCIATE MEMBERS—

MR. J. H. CUMBERBATCH, 51, Furnace Road, Longton, Stoke-on-Tent.

MR. A. MOFFATT, 67, Broade Street, Fenton, Stoke-on Trent.

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER—

MR. H. MASON, Parkhall Colliery Company, Limited, Cheadle, Stoke-on-Trent.

THE APPLICATION OF SUBMERSIBLE ELECTRIC MOTORS TO MINING WORK.

BY A. J. RAMSAY, A.M.I.E.E.

Introduction.—At the time of writing this paper the question of pumping in all phases of mining work is of the utmost importance, not only to the mining engineer, but also to the whole of the community, in view of the disastrous stoppage of work in the mining industry and the consequent flooding of the mines or lower workings in a number of areas.

It is hoped that this paper will contribute something to the solution of the various problems with which the mining engineer is faced in bringing conditions back to normal, and that it will also show that it is possible to install pumping plant in future that will not be affected by flooding, due to stoppages or accidents, and which can be relied upon to work satisfactorily after indefinite periods of submersion.

Although the present paper is confined to the various pumping operations met with in mining work, I am confident that the submersible motor can be applied also to other duties.

Development.—One of the greatest problems that has engaged the attention of electrical engineers during the present century is a method of insulating the windings of electrical machines so as to enable such machines to work satisfactorily in damp or wet positions.

Prior to the invention of the submersible electric motor by Macdonald in 1908, the only method attempted by manufacturers of dealing with the problem as applied to electric motors was to construct what were termed "watertight machines." These machines were, of course, totally enclosed, with special precautions taken to keep moisture from entering the interior.

Even the best designed machine of this type is very unsatisfactory, as the alternate heating and cooling of the iron and copper within the machine has a very damaging effect on the insulation of the windings. Further, the output of machines of this type is limited on account of the amount of copper and iron required for a given horsepower output, and above a medium power the weight and cost become prohibitive.

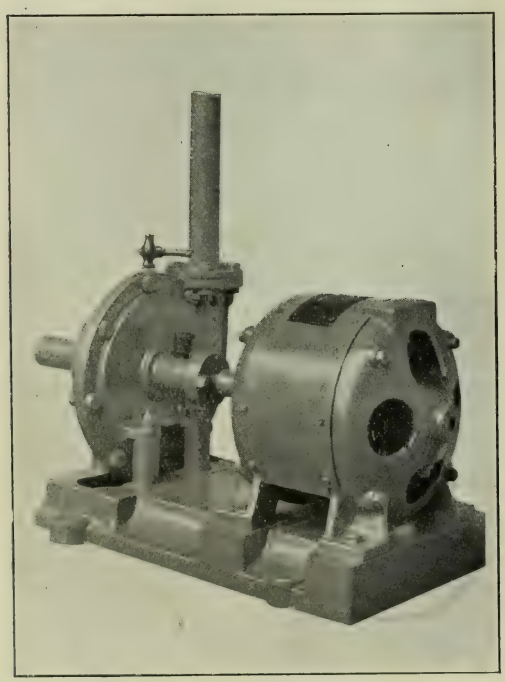


FIG. 5.—MACDONALD'S FIRST SUBMERSIBLE MOTOR.

Macdonald succeeded in designing a motor in which it would be possible to use water or other liquid as a cooling agent. The principle on which he worked, which holds the field to-day, was to pass water completely through the windings of the machine and to insulate the conductors for these conditions.

The first machine produced was a crude arrangement, as will be seen from Fig. 5 in the text, but it demonstrated the practicability of the idea. The motor-frame was open, admitting water to the interior, and it will be noticed that it was necessary to have the motor submerged at all times when working, in order to obtain the necessary cooling for the windings. It will also be obvious that the design of the bearings would not be suitable for continuous operation.

Since Macdonald's time, and particularly since the year 1914, great changes have been made in the design and method of application for various duties.

The present paper is confined to a general description of the modern submersible motor, particularly as applied to pumping plant for use in mines, the motor in all cases being of the squirrel-cage induction type. No attempt is made to deal with the theory of the induction-motor or the centrifugal pump, and members desiring information about these machines should refer to the many good books and papers already written on this subject.

It would be well to state here the chief points that a mining engineer looks for in an electric motor for which he is to be responsible. These are:—

(1) Reliability, particularly as regards the risk of the motor being flooded, and when installed in a fiery mine.

(2) Portability, particularly with reference to sinking-pump sets, and those for use in headings.

(3) Low maintenance cost.

(4) Highest possible efficiency.

(5) Moderate capital cost.

(6) Minimum space.

(7) Possibility of running for long periods without attention.

(8) Remote control.

The foregoing advantages can all be claimed for the submersible motor.

Description of a Submersible Motor and Single-stage Pump.—A description of a submersible motor direct-coupled to a single-stage centrifugal pump of the portable type will now be given, together with photographs showing the component parts.

Fig. 6 in the text shows a complete machine of the following duty:—Pump: 750 gallons per minute, at 75 feet T.M.H.; motor: 30 horsepower, 1,430 revolutions per minute, three-phase, 50 periods, 220 volts. The maximum dimensions of this set are: length, 52 inches; width, 27 inches; height, 37 inches; total weight, about 17 cwt.

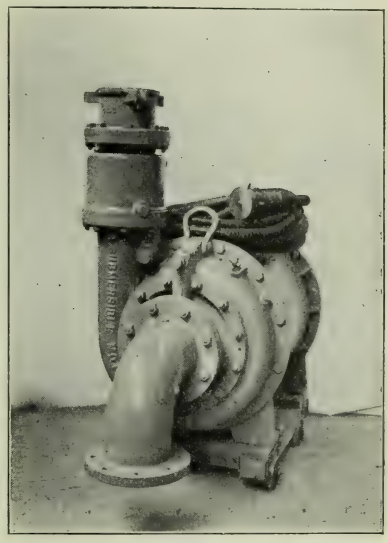


Fig. 6.—Portable Submersible Motor-pump.

It will be noted that the pump is coupled direct to the motor-frame, thus making a very compact unit. The shaft is made of manganese bronze, with the squirrel-cage rotor and the gunmetal pump-impeller mounted thereon.

With regard to the rotor construction, the end rings are brought close up to the iron at each end. This is important, for the following reasons:—(*a*) In the final assembly of the bars and end rings the core is compressed by these members right up to the periphery of the core-plates, thereby preventing the spreading of the plates, which would open up pockets for corrosion. (*b*) If the bars passed the edges of the core with a gap, before linking with the short-circuit-rings, according to usual practice for an air-machine, the water losses which are inevitable would be greatly increased. (*c*) A very robust construction is obtained and the exposed surfaces are reduced to a minimum.

The bars are made of drawn copper, and are enamelled where they pass through the core. Each end of a bar is drilled in the centre for a distance equal to the axial length of the end ring; steel pins are driven into the holes, thereby swelling the end of the bars and making positive contact with the end rings. Before assembly, the ends of the bars and the holes in the rings are tinned, and after assembly the whole of the joints are sweated up.

There is no danger of heating on account of the water cooling, so

that there is no trouble from sweated joints. For larger units, however, the bars are welded to the rings.

The impeller is of the single-inlet type, cast in one piece, with blades having the form of involutes at entrance and exit.

The whole of the component parts for this motor-pump are shown in Fig. 7. The motor-stator (1) is a totally-enclosed cast-iron frame, and the core is assembled under pressure with stiff-ribbed end-plates which completely cover each end of the core. The winding takes the standard form for three-phase, single-layer, star-connected type, with a two-plane overhang.

The conductors are of circular cable, built up of a large number of finely-stranded and tinned-copper wires, insulated with a special preparation of indiarubber. The lays of the strands are so arranged as to give a minimum diameter for a given cross-sectional area, and to make

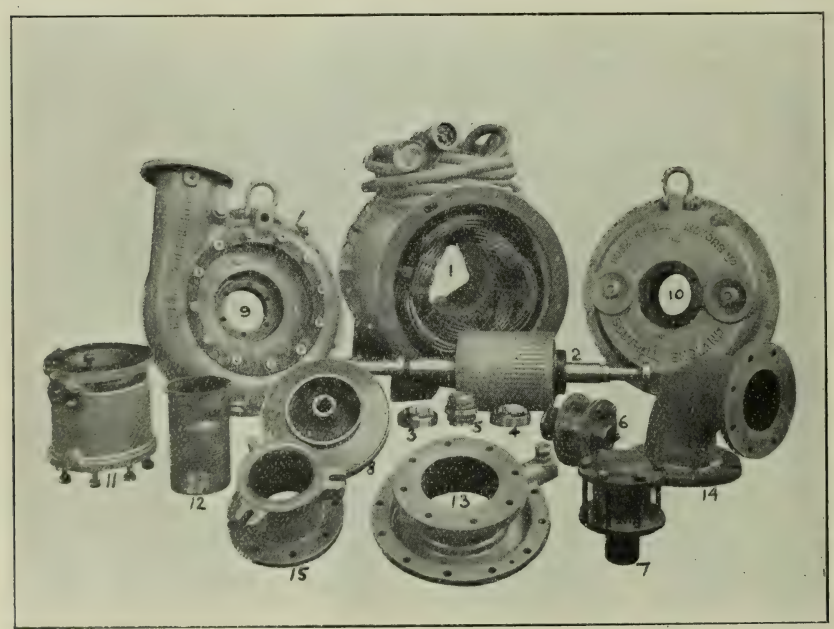


Fig. 7.—Component Parts of Motor-pump shown in Fig. 6.

possible an easy and safe bend on the overhang. By this means there is complete continuity of insulation throughout each phase of the winding. The star point is carefully spliced and vulcanized in a special mould. In this type of machine the free ends of each phase are brought out through a stuffing-box on the motor-frame for a length of about 50 feet, and there terminate in a three-pole watertight coupling, to which reference will be made again. The extended cables are protected by armoured rubber hose. The overhangs of the coils are clamped securely to the motor-body.

The iron core-plates of both stator and rotor are treated with a special varnish, each plate being passed through a machine resembling a domestic mangle, the rollers of which revolve in the liquid. By this means an even layer of varnish of mimimum thickness is applied to each plate, thus effectively sealing the joints in the assembled core. (2) is the rotor and shaft, and (8) the impeller already referred to. (3) and (4) are steel roller-bearings for the radial load, and are mounted in gunmetal

housings (6) and (7). (5) is a double-thrust ball-bearing, which locates the rotor axially and takes the thrust due to the pump. This bearing is mounted with one radial bearing in housing (7), and the whole is carried in the motor end-bracket (10). The housing (6) is carried in the volute casing (9), which forms the other end-bracket of the motor.

The water-channel within the volute is of standard design, with gradually increasing sectional areas in the direction of rotaton of the impeller. The boundary-line of the volute is such that it conforms to the actual angle of discharge of the water from the impeller. (11) is a filter-body attached to the discharge flange, and into the centre of this body is fitted a brass cylinder (12), the inside diameter of which is equal to the diameter of the discharge-pipe. The function of this filter will be

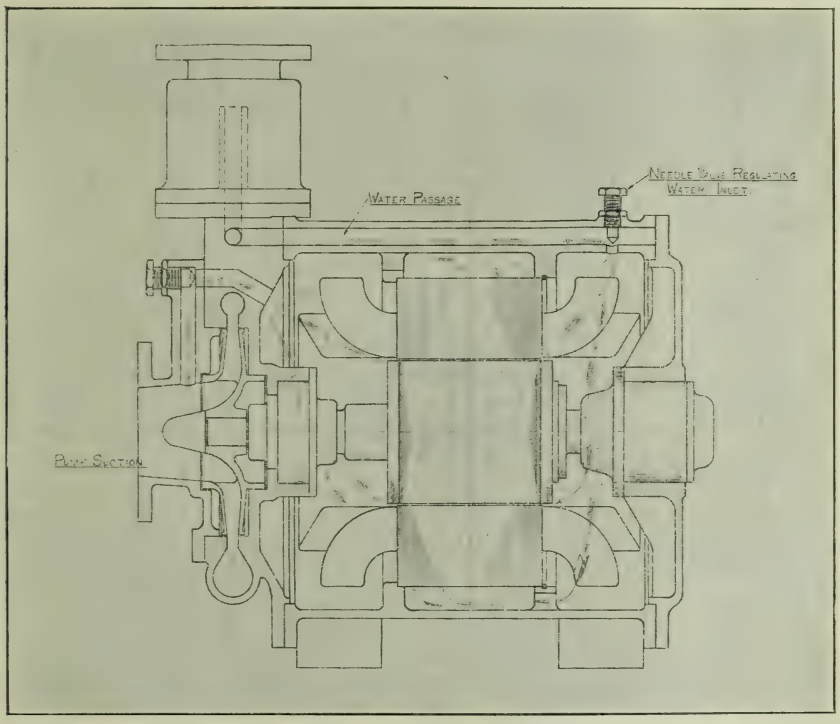


Fig. 8.—General Arrangement of Motor-pump, with Arrows showing Water-circulation.

described later. (13) is the pump suction-cover, which is attached to the volute (9), and the bend (14) is attached to (13). (15) is a swing-bolt adaptor-coupling for the delivery-pipe.

Cooling-water Circulation.—In Fig. 8 the arrows indicate the paths taken by the water from the pump to the motor and back to the pump. The water in this type of pump is taken from the filter previously mentioned, which is mounted on the pump-discharge. The brass cylinder through which the water passes is provided with a large number of openings about $\frac{3}{4}$ inch in length circumferentially and about 20 mills (0·020 inch) in width axially. These openings lead into an annular chamber of ample dimensions surrounding the brass cylinder, in which chamber the water moves at a very low velocity.

For this size of machine 10 gallons per minute are quite sufficient

for perfect cooling of the motor, which represents, say, 1·33 per cent. of the total quantity delivered by the pump.

The water passes from the filter-body through cored passages along the top of the motor-body, and passes to the interior of the motor through a hole, the area of which can be regulated by the adjustable needle-valve shown. Within the motor the water may take several paths. Some passes through the air-gap, a larger quantity passes through the annular chamber between the core-plates and the motor-body, and a further path lies between the conductors from end to end of the slots in the stator-core. A reference to Fig. 9 will show the excellent cooling effect obtainable on each conductor. The water finally passes through connecting passages into the pump-suction, the area of opening on the suction being again controlled by an adjustable needle-valve.

From the foregoing description it will be seen that the modern machine differs from the original in one very important respect, namely, that whether the machine be above or below water, the motor always receives a positive supply of cooling-water.

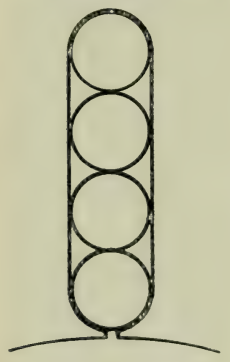


FIG. 9.—SHOWING CHANNELS BETWEEN CONDUCTORS THROUGH WHICH COOLING-WATER CAN PASS.

The roller- and thrust-bearings, which are mounted in gunmetal housings filled with grease for lubricant, are practically surrounded by water at all times, and are therefore prevented from heating.

For machines in permanent positions, and in cases where they are likely to be submerged for long periods in inaccessible positions, the bearing housings are fitted with automatic lubricators, to which reference will be made later. This type of machine should be extremely useful in "headings" and "deeps," particularly as it can be worked in every conceivable position without alteration of any description. Fig. 10 shows the characteristic curves of one of these machines.

At 750 gallons per minute the pump delivers at a pressure equal to 78 feet. The overall efficiency of the motor and pump at this point is equal to 56 per cent., the power-factor of the motor is equal to 87 per cent., and the input of the motor is 32 horsepower. It will be noted that the maximum power input with the pump delivering at reduced heads down to zero is only 35 horsepower, which represents a maximum increase of only 9·4 per cent. on the normal full-load horsepower.

These tests were taken with the pump submerged; with the same machine running on suction, the set is practically self-regulating, which shows the good results that can be obtained in this respect by correct design of the impeller blades and suitable proportions for the pump-casing.

As a comparison, Fig. 11 gives similar curves for a 4-inch pump delivering half the quantity of water at the same pressure. The pump is of older design, and it will be noted that although the characteristics are quite good the horsepower input curve rises more steeply.

Portable Sets in Workings.—In dip or deep workings this type of motor-pump should prove indispensable as auxiliaries to the main pumping sets, and particularly where used for de-watering old workings. The gradient of the working is immaterial, and by mounting units

on a suitable skid or trolley and coupling sufficient sets together in series any conceivable problem could be tackled.

The question of coupling up the feeding-cable supplying the motors

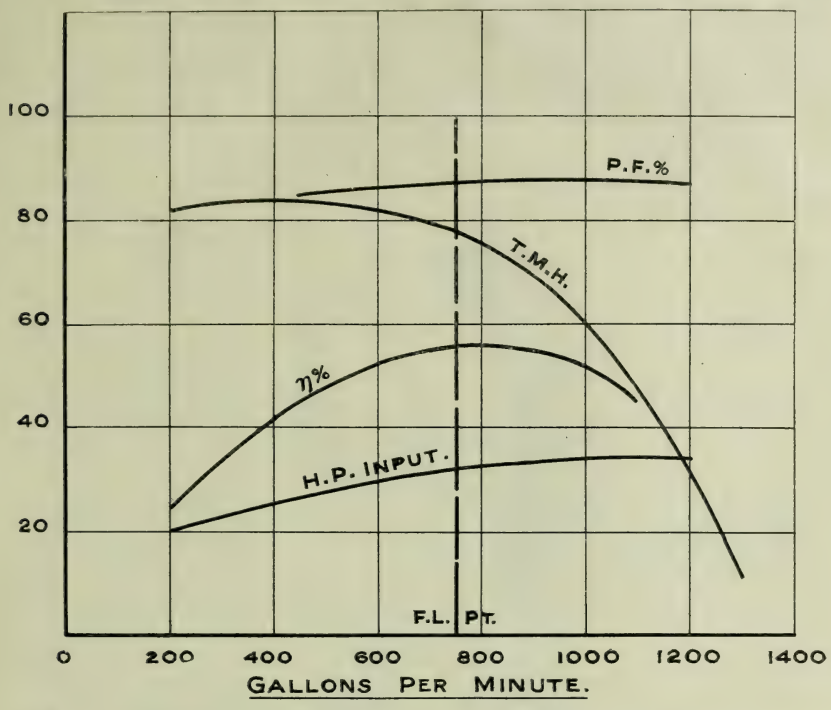


FIG. 10.—PERFORMANCE CURVES OF A 6-INCH SUBMERSIBLE MOTOR-PUMP.

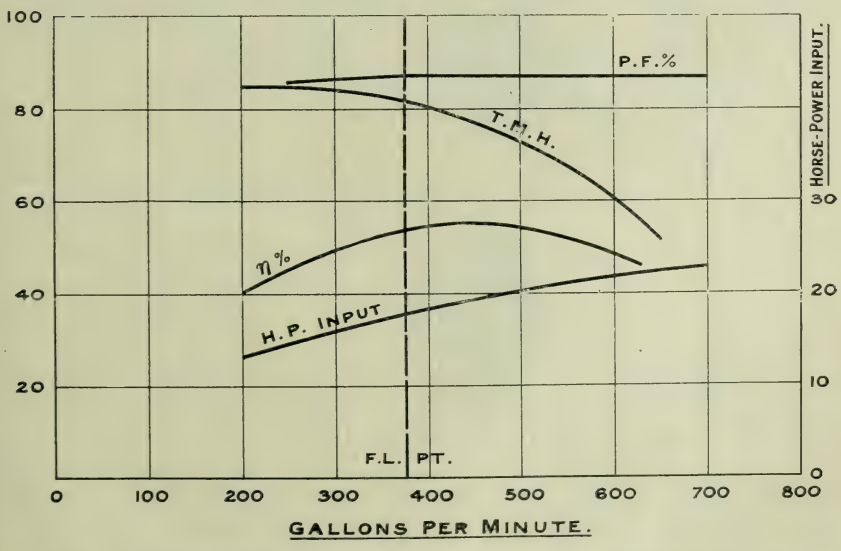


FIG. 11.—PERFORMANCE CURVES OF A 4-INCH SUBMERSIBLE MOTOR-PUMP.

is of very great importance. The cable would generally contain four cores, one of which would be connected to earth. In order to keep the cable winding-drums down to a suitable size, and to facilitate handling,

the lengths should not exceed 100 feet for medium-power machines. Cable-couplings for this work should comply with the following conditions:—

(1) Robust construction, combined with minimum weight.
(2) Be absolutely watertight.
(3) Fixed phase relation—that is, it must be impossible for the two halves to go together in the wrong position.
(4) Comply with Home Office Regulations.
(5) High insulation resistance.
(6) Ample contact areas.

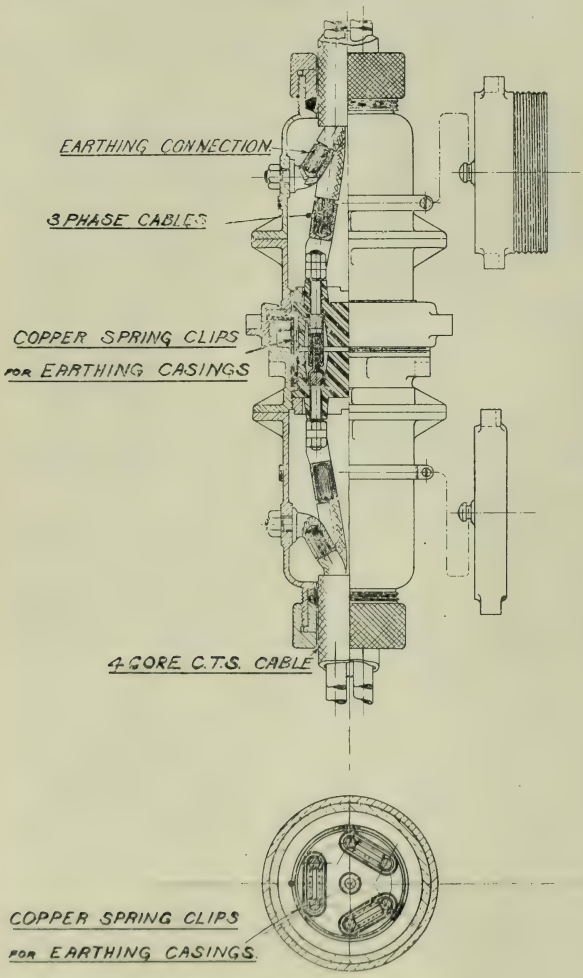


Fig. 12.—Submersible Four-pole Cable-coupling for Earthed Systems.

The above-mentioned points are satisfactorily embodied in the "submersible" cable-coupling. Fig. 12 shows an assembled view of a complete coupling. The case is made of naval brass, and the block in which the contacts are mounted is of non-hygroscopic fireproof material of high insulating properties. The electrical contacts are of hard drawn copper of the "knife" pattern, riveted to gunmetal blocks sunk into recesses in the insulating block, and arranged so as to give a long leakage path. Two copper studs are screwed into each contact-base, and these pass through holes in the insulating block and are fixed with an independent locking-nut. Connected to these studs are the three sweating sockets. The fourth or earth-connexion will be seen securely bolted to the coupling case. The distance between the end of each half coupling and the top of the contacts is such that the male and female contacts are completely separated, when breaking a joint, before the casings become parted. Similarly in making a joint the "earth" is made first.

In order to ensure that a good earth contact is made between the

two half casings, three flat copper strips fixed in equidistant positions around the plug half spring into suitable seatings on the other half casing. The joint between the two halves is made on a flat machined surface with a packing-washer, which is pulled tight by a stiff locking-nut. Covers are provided for protecting the contacts when not in use. A stuffing-box is fitted at the neck of each half-coupling, which serves the double purpose of making the interior watertight and of relieving the cable-connexions of mechanical stress.

In cases where the cable armouring is used for earthing purposes, a modification is necessary at the neck of the coupling, and such an arrangement will be described later in connexion with a large pumping set for sinking work

The insulating block is provided with a locating feather, which is in a fixed position with reference to the exterior feather.

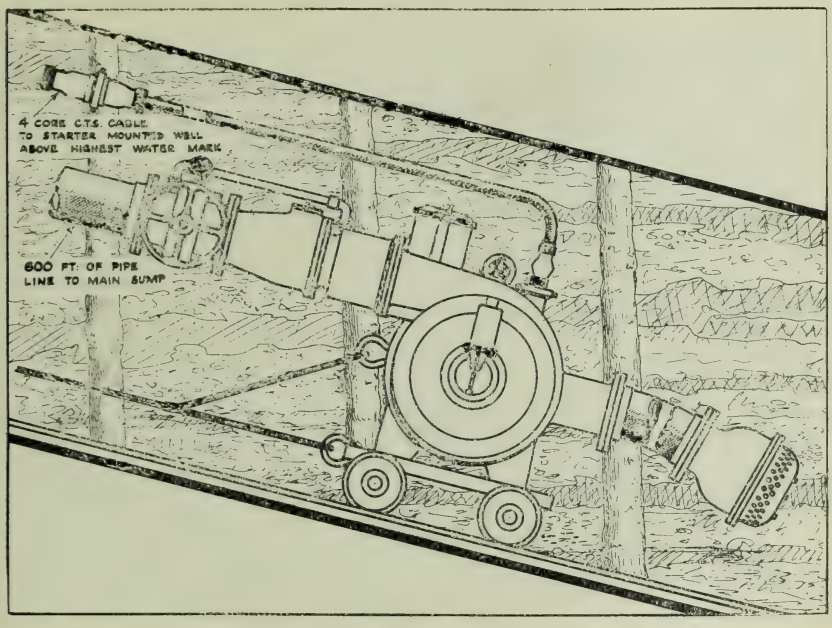


Fig. 13.—Portable 6-Inch Double-inlet Submersible Motor-pump in Dip Workings.

Fig. 13 is a drawing of a 6-inch double-inlet pump coupled to a 50-horsepower motor installed in a mine in Gloucestershire for use in " dip " workings. The set, as will be seen, is mounted on a trolley. Fig. 14 gives the curves of the motor-pump taken on test.

De-watering Shafts.—From the description given, it will be agreed that the submersible motor-pump is eminently suitable for pumping out shafts and pits. The following additional advantages may be briefly stated:—

(1) The whole unit may be submerged, thus eliminating the necessity for suction-pipe and foot-valve, with the attendant losses and troubles on the suction.

(2) Great saving in time and labour, as delivery-pipes and feeding-cable can be fitted in one operation, providing for a lengthy run before it is necessary to shut down again for adding additional lengths.

As an example of what may be accomplished, an operation carried out at an old mining shaft will be described. It was necessary to find in

this case the yield of the shaft at a depth of 300 feet from the surface, the shaft being about 500 feet deep and 12 feet in diameter. A suitable high-lift pump in one unit was not available at short notice, and it was decided to use four 6-inch sets coupled in series, each of which was to be of the capacity and design of the set already described in detail. The motor-pumps were coupled together in pairs, with the delivery of the first bolted direct to the suction of the second. The arrangement will be seen in Fig. 15, which is a photograph taken at the head of the shaft.

A start was made by lowering the first pair to a depth of about 150 feet, the water then being within 11 feet of the surface. In five days the water-level was lowered to the level of the pumps, and then the second pair were joined in series and the whole lowered, so that the bottom pair were about 310 feet down. After a further seven days the water-level was lowered to 275 feet from the surface, and a continuous yield of about

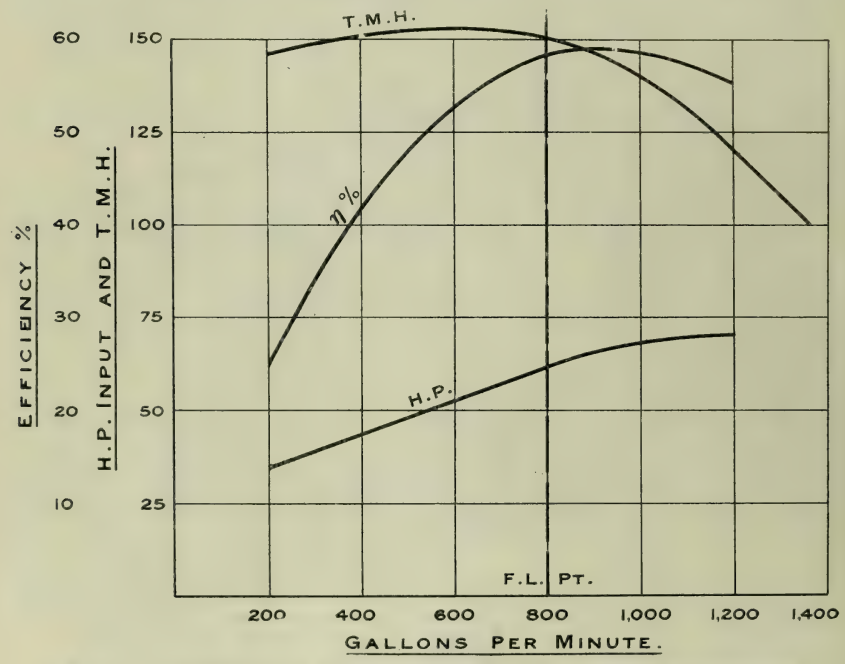


Fig. 14.—Performance Curves of 6-Inch Double-inlet Submersible Motor-pump shown in Fig. 13.

33,000 gallons per hour was obtained at this level. Altogether the plant was running for thirty-seven days, one pair running for twenty-four days on end, and on nineteen of these days for 24 hours per day.

The bearings of these machines were all fitted with automatic lubricators (Fig. 15) in the form of a cylinder mounted at each end of the machine, with a pressure-pipe connexion entering the top of the cylinder. A detailed description will be given later in connexion with a large sinking set. Mining engineers will appreciate the difficulties which had to be overcome in lowering plant into an old shaft such as this, with unknown projections obstructing the gear and quantities of *débris* of all descriptions in the shaft. The only pipe-line available was a screwed-joint M.S. tube, and this was clamped in sections together with the feeding-cables to the single-suspension wire rope. A short length of flexible pipe was fitted on the suction side of the pair nearest the top, in order to compensate for varying lengths in suspension.

No other machine known to the author could have been used in such a manner, and the necessary information was obtained without the expense of the provision of special plant f r the purpose of obtaining the yield of the shaft.

Pumping at Pengam Colliery, Monmouthshire.—A further example of de-watering carried out at Pengam Colliery entirely with portable generating and pumping plant will now be given.

The old pit at which operations took place is situated in a valley, at such a level as to drain the water from the workings in the hillside, the shaft being about 8 feet in diameter and 120 feet deep. The electric supply was not laid on when operations commenced, and use was made of a paraffin-oil engine driving an alternator supplying 35 kilo-volt-amperes at 220 volts, three-phase, and 50 periods.

Fig. 16 shows the arrangement of the generating plant, with a switch-

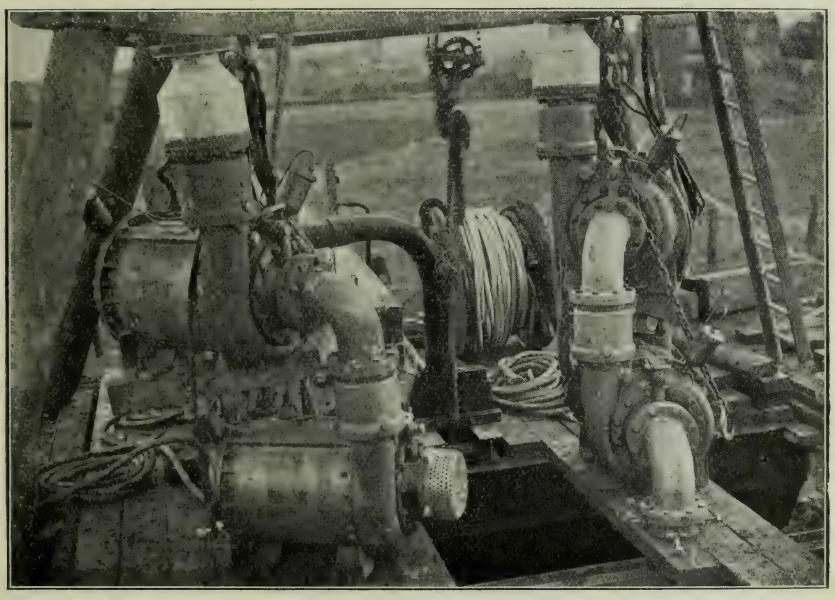


Fig. 15.—Four Single-stage Submersible Motor-pumps Coupled in Series for Shaft-pumping.

board containing a voltmeter and ammeter, and with a three-pole fuse-switch of the ironclad type. Connexion is made from the switch to an auto-transformer starter and thence by three-core C.T.S. cable to the motor-pump. The 6-inch motor-pump used was of the same duty as previously described, and was fitted with automatic lubricators. The pump was suspended during the whole operation by a wire rope. Pumping was commenced on May 6th, 1920, and the motor-pump was removed on April 13th, 1921, when it was replaced by another submersible motor-pump of larger capacity. Altogether the pump ran for 281 days, with an average of 19 hours per day, although the pump very often ran for weeks together for 24 hours per day. The average working head was 60 feet, and the quantity of water delivered 60,000 gallons per hour.

The machine was brought to the surface twice for examination during the summer of 1920, and was found to be in perfect condition. For the last six months of the period of working the motor-pump was entirely

submerged, and no examination of any sort was made. Such a performance for an electrical machine is, I believe, without parallel.

The set was returned direct to the works, after being raised on April 13th, 1921, and the following is a brief report of the condition of the machine :—

Insulation test of motor windings, in water : 8 megohms.

Bearings : In good condition.

Grease lubricators : Thrust end nearly empty and housing full; motor end half full and housing full.

Shaft : In perfect condition (as there are no tight-fitting glands).

Machine coated inside and out with red-sand deposit.

Fig. 17 shows the machine as it came out of the pit. It will be seen that a rough wooden platform was built over the machine, and this was used by sinkers in the summer of 1920 as a platform when working down

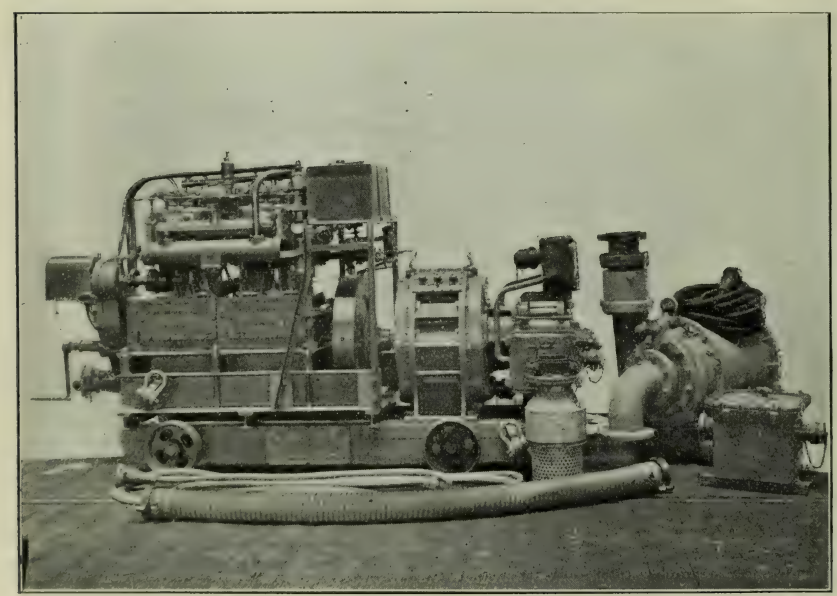


Fig. 16.—Pumping Plant used at Pengam Pit.

below. A considerable amount of sinking work was carried out with the aid of this pump, and the sinkers engaged on the work were very surprised at the lack of trouble with the pumping arrangements, which they stated was quite an exceptional experience. In a small shaft such as this it was found a great convenience to have the pumping plant beneath them, and thus have provided the maximum space for lifting buckets, etc.

Sinking-pumps.—An example of a sinking-pump, which I have recently designed throughout at the works of Messrs. Submersible Motors, Limited, will be cited as representing the latest practice in this type of machine. The machine is for mine-shaft sinking in China, and it will be seen from the following description that several novel features are incorporated in the design. The duty is as follows :—Pump : 1,000 gallons per minute at 600 feet T.M.H. ; motor : 280/300 horsepower, 1,460 revolutions per minute, 380 volts, three-phase, and 50 periods. Figs. 1 to 4 (Plate IV.) show a sectional arrangement of this set, and it will be

noticed that for mechanical reasons the pump and motor are separate units. The motor is of the standard squirrel-cage submersible type, constructed generally on the lines as described in detail in the earlier portion of this paper. The end windings are protected by a split cylindrical casing of metal, in order to prevent damage to the windings when removing or assembling the rotor. This casing is tied to the motor-frame by studs not shown on the drawing.

The three leads to the stator-windings pass through separate stuffing-boxes to the cable-coupling, which is mounted direct to the top cover of the motor. This coupling is constructed in much the same manner as those previously described, but special provision is made for extra strength in the casing on account of the stresses likely to be put upon it when raising and lowering the set. The two halves of the coupling-case are bolted rigidly together, and the casings are pressure-tested before assembly. It will be seen that the armouring of the three-core feeder is clamped and effectively earthed in the neck of the top half coupling. After the connexions are made, the whole of the interior is filled with insulating compound. The coupling is capable of carrying 500 amperes continuously.

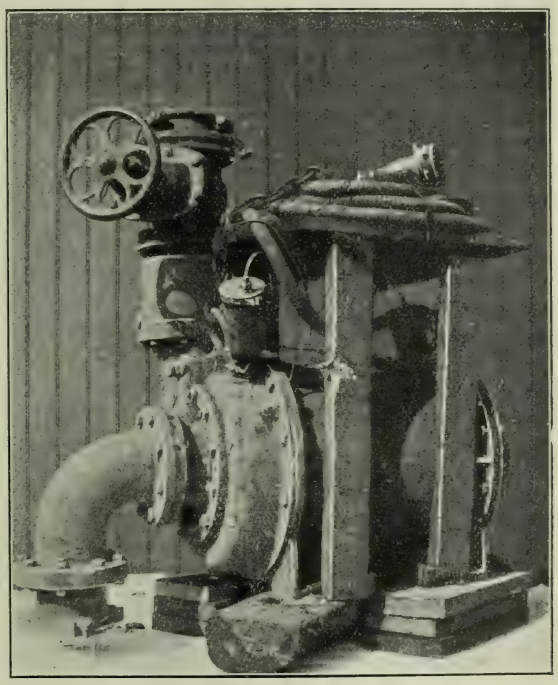


Fig. 17.—Motor-pump as removed from Pengam Pit.

The three radial bearings are of the rustless-steel roller type, and are contained in housings filled with grease as lubricant. A "Michell" thrust-bearing of liberal rating is provided at the top, and is specially mounted in a housing surrounded with a water-jacket. The top cap of the housing is specially shrouded to project over and protect from damage the two oil-circulating pipes of the thrust-bearing. The principle of the automatic lubricators attached to the three radial-bearing housings will be understood by reference to the drawings. A cylindrical casing with a bottle-neck which connects to the housing interior is filled with grease lubricant, and a packed piston is placed on top of the lubricant. A cover seals the free end, and the pressure-pipe connects the space on the top side of the piston with the interior of the motor-body or pump. The pressure exerted at the nose of the bearing housing at any time and under all conditions is thus balanced by the piston exerting an equal pressure through the lubricant at the rear of the housing. By additional mass in the piston, or by other means, an excess of pressure can be arranged for within the lubricator to ensure

that the housing is continuously filled. It will be obvious that very prolonged running without attention can be provided for, which is of vital importance in sinking operations. A charging-cylinder is fitted at the top of the set, from which point the lubricators when necessary can be filled with grease. This operation will easily be understood from the drawing. Each lubricator is connected by a pipe with the charging-cylinder, and a turn-cock is provided in each connecting-pipe immediately beneath the cylinder, thus giving independent control. The water for cooling the motor is taken from the back of the last-stage impeller and passes through ducts around the stuffing-box, thus providing effective cooling at this point. The water passes through a regulating-valve into a double filter shown on the right-hand side of Fig. 1 (Plate IV.). The first portion of the filter is similar in design to that already described in this paper, and is provided at the free end with a " dished " cover to receive sediment. A cover of the " Nunan-&-Stove " pattern is fitted at the bottom of the " dish " to enable accumulations of sediment to be quickly blown out. Direct coupled to this filter is another of different design, the water in this case passing through cylinder walls of very fine wire gauge mounted on a stiff spider. It will be seen that it is possible to withdraw both filters for cleaning, without disturbing the pipe-connexions. Provision is made for duplicating the filters, if found necessary. Seeing that the water has to pass the impeller clearances before entering the filters, the size of particles of foreign matter is limited at the outset. A further control-valve is fitted in the supply-pipe at the entrance to the motor. The arrows show the direction of the water passing upwards, and finally around the thrust-bearing housing, thence by a pipe to the pump-suction.

It was considered advisable on a set of this size to provide some safety arrangement in connexion with the cooling-water for the motor.

The pump may be submerged for long periods when examinaton is impossible, and the filter or passages connecting the same may become blocked and the motor thereby seriously damaged. An inlet-valve (Fig. 3. Plate IV.) is provided on the top of the motor. This valve is controlled by a spring, and is surrounded externally by a perforated casing, which acts as a filter. If for any reason the main filtering system fails to operate, then, owing to the reduction of pressure within the motor and the pressure of water on the exterior, the valve will open and admit water for cooling the motor. Further, if the pump be running on suction, this valve would admit air under the above conditions, which would pass to the pump-suction, thereby reducing the output of pump and the load on the motor. The operator would have his attention drawn to the trouble by both the pump-gauges and the electrical instruments.

The complete machine is mounted in a slinging-frame with a wire-rope pulley for double suspension. The delivery-pipe passes up between the two ropes, and the whole weight of the pipe is distributed over the slinging-frame.

Main Pumping.—The submersible motor is certainly as desirable for main pumps as for the other duties already dealt with. With control-gear mounted in a " safe " place, the motor-pump is not in danger of being ruined when pits are suddenly shut down and labour withdrawn. In addition, there is no necessity for choosing " safe " positions for the pumping plant, so that great flexibility is allowed the engineer in choice of position and in placing the pump in the position giving greatest utility.

In places where it is desirable to have control-gear near to the motor-pump for convenience in working, I would suggest that dual control-gear be fitted at some point always accessible under the worst conceivable conditions. The additional capital cost would be only a small insurance premium against the destruction of expensive plant.

In conclusion, I wish to thank Submersible Motors, Limited, for permission to make use of the data contained in this paper.

The PRESIDENT (Mr. J. R. L. Allott): The idea of associating water with electricity strikes something like horror into the minds of mining and electrical engineers; and I think that, however successful the submersible motor may be, engineers will always, wherever possible, avoid associating the two. Nevertheless, many circumstances do arise in which it may be possible to apply apparatus of this kind with advantage.

Credit is due to the designer for boldly tackling the idea of an open type of electric motor that will work under water. Totally-enclosed motors, intended to work under water, are rarely entirely satisfactory, and if reliability under the conditions which submersible motors are designed to meet can be assured, there ought to be a field for them—at any rate, in small units.

In considering the paper from the standpoint of a mining engineer, several points occur to me. I gather that the motor must be of the alternating-current type. Consequently, where the supply is direct current, a motor-generator set is necessary. This may be a matter of little moment in the case of small pumping sets; but, if large sets are to be employed, this means the installation of expensive and wasteful converting machinery, or the provision of new alternating-current generating plant.

It would be interesting to know whether the supply voltage is limited to low tension—say, not exceeding 400 or 500 volts. Does the author recommend submersible motors to be wound for high tension—say, 2,000 to 3,000 volts? If the motor voltage is to be limited to low tension, this again means, in large sizes, the use of either static transformers or of heavy and expensive cables.

I notice that every motor mentioned in the paper is of the squirrel-cage type, and assume that a wound rotor is scarcely admissible under the circumstances. Perhaps the author will say something on this point. While one would prefer a squirrel-cage motor to a wound-rotor motor where circumstances are favourable to the employment of the former, if my assumption in regard to the submersible motor is correct it means that it cannot be employed for large duties on power installations of only moderate capacity, on account of the large starting current which it will take. It is interesting to know that a pumping set, with a squirrel-cage motor of as large as 300 horsepower, has been shipped to China, but I gather that this set had not run on the date when the paper was written. Perhaps Mr. Ramsay could tell us what the source of supply was in this case and the capacity of the generating station.

My point is not the limit to the size of the motor as a motor, but the shock to the generating plant in starting if this is not of ample capacity. My experience of squirrel-cage motors is that I do not like to employ them above 150-horsepower with a 1,000-horsepower generating plant.

The point of supreme importance to the mining engineer is reliability, and if, by adopting a special type of apparatus, he is lulled into a

false sense of security, and then finds that he is mistaken, the consequences are generally much worse than if he had installed standard plant and taken the usual precautions against the possibility of trouble. It appears that the only protection provided for the iron or steel portions of the motor against the action of impure water is a layer of some special varnish, which does not strike me as being a very satisfactory job for a colliery. Supposing, for instance, that in assembling the parts of the motor the varnish is scratched—a very easy thing to happen—corrosion is then bound to take place in time, and no matter how perfect the layer of varnish is elsewhere, the corrosion, once started, will spread.

Has Mr. Ramsay any experience of submersible motors working in collieries where the water is acid? There are many pits in this country in which the water is so bad that it will completely destroy iron in a few months. I have had personal experience of this, and had to install pumps made entirely of phosphor-bronze in order to overcome the trouble.

The motor works by water bye-passed from the pump on the delivery side, and the water which passes through the filter-body and the motor is controlled by a needle-valve. This valve has obviously to be adjusted while the plant is above water. I can imagine that needle-valves will give trouble, as fine sediment will sooner or later choke them up, prevent circulation of water through the motor, allowing it to become overheated, and cause a breakdown. Those who have had experience with turbine pumps, most of which are fitted with balance-valves, know that the sediment from pit-water causes trouble.

Mr. Ramsay has brought to our notice a most interesting and useful type of motor for pumping, which will doubtless receive much attention from mining engineers. There are many cases in which these motors and pumps can be usefully employed, but it has to be borne in mind that colliery work is necessarily rough work, and the conditions in pits where pumping has to be done are generally worse than the ordinary colliery conditions.

I have a note here of a motor used under water at the Tate Sugar Refineries, Liverpool—a pump taking about 200-horsepower, with a motor direct-coupled to it, and the motor placed in a diving-bell. Normally, during the week, the water is below the pump—that is to say, when pumping; but, at the week-end, when the pump is standing, the water rises to a height of from 120 to 130 feet over the pump, the motor being protected by being in the diving-bell, with compressed air inside it.

Mr. W. Tyson (Longton): The President has covered quite a number of the electrical points about which I had intended to speak. There is, however, just one point which struck me with regard to the set illustrated in the Plate (Figs. 1 to 4). It is laid out for armoured cable, which, I presume, will be submerged with the pump. I should like to know what type of cable the author would propose to use in this case.

Mr. J. Parkinson (Stoke-on-Trent): There are two points in connexion with which I should like further information.

First, the conductors forming the stator winding are insulated with rubber. Can the author say whether this insulation is pure rubber, or vulcanized rubber, or a combination of both?

Secondly, according to the illustration in the paper, it appears that the slots in the stator-core are practically closed at the top, and in consequence the cable forming the stator winding will have to be threaded through the slots. This will necessitate very careful handling of the cable

during the process of winding, in order to prevent abrasion of the rubber insulation.

Further, it is usual to pack the stator winding rigidly in the slots by means of wedging strips introduced after the winding is in position. In this particular case, apparently, the elasticity of the rubber insulation is relied upon to hold the conductors tightly in the slots. There is sure to be a certain amount of vibration set up when the motor is running, and it would be interesting to know what effect this vibration has on the rubber insulation, and whether there is any tendency or not to chafing between the stator core and the rubber insulation, which would eventually cause a breakdown.

Mr. A. J. Ramsay (Southall): I am much obliged to the President for his criticism, which raises points of practical importance.

He has raised the question of a direct-current submersible motor. It is a fact that machines of the type described in this paper—that is, with water passing through the windings of the motor—are at present designed only for alternating-current motors with squirrel-cage rotors. The design of a direct-current submersible motor is a much more difficult problem, and one not easy of solution. A great deal of thought has already been given to the problem, and there are ways and means of solving it. I do not know of any proposal, however, for a direct-current submersible motor which can be used in the form I have described to you. One proposal is to put a direct-current motor into the top of what may be called a "diving bell," with a pump mounted on the bottom of the bell and coupled to the motor by the necessary length of shaft. The motor is prevented from being submerged by a compressed-air chamber in the top of the bell. I believe that there is a machine on the market designed somewhat on the above lines, but I have no practical experience of it, and it is obvious that the application of this type of machine is limited. For instance, it is absolutely necessary that it should be fixed in a vertical position, and that the maximum depth of submersion should be predetermined. The example quoted by the President of a machine at Tate's Sugar Refinery is more or less the same principle as that just described. The conditions were known, and the air-chamber could be made of sufficient capacity to agree with these conditions.

With reference to the question of an induction-motor with wound rotor, I do not think that this is impossible of solution—although it opens up many more difficulties, particularly in connexion with the slip-rings and brush-gear. A machine of this type has not yet been put into service. It would prove more costly, and the starting-gear would be more expensive and elaborate. The squirrel-cage rotor is so simple, and what one might term practically foolproof.

The President mentions the question of large units, and I have in the paper described a 300-horsepower pumping set with a squirrel-cage rotor. Two of these sets are being installed under the direction of a very eminent consulting engineer, and the supply for these two motors will be taken from the Pekin Chinese Electric Light and Power Company. The power-station is about 13 miles from Pekin, and about 5 miles from the colliery where the two pumping sets are being installed. The capacity of the power-station will be 30,000 kilowatts, and the pressure at the station 33,000 volts. Step-down transformers are used for a supply at the colliery at a pressure of 380 volts.

I do not think the application of the squirrel-cage induction-motor is

limited to machines of small-power in connexion with centrifugal pumps. As a rule, sufficient starting torque can be obtained from a squirrel-cage rotor to start a centrifugal pump with a starting current of 1 to 1½ times full-load current. I should be pleased if mining engineers would inform me of the largest machines of the squirrel-cage type they know of in operation. In any event, I think that continental firms have put in much larger units of the squirrel-cage type, and have applied this type of motor more generally than has been done in England.

With reference to the problem of building the submersible motor for high tension, I see no difficulty in designing a machine at least up to 2,000 volts between phases, provided that the horsepower of the motor is not so low as to bring the size of the winding-cable too small for obtaining satisfactory and even distribution of insulation. Machines have already been designed for 1,000 volts, and there is no reason why they should not be used for much higher pressures. With regard to the large sets for China, described in the paper, I am sorry that the test figures for these machines are not yet available.

The President also raised the question of the use of submersible motors in water containing acid. There is no difficulty in this respect, as regards the windings of the motor, and doubtless it would be possible to construct the carcase of suitable material and take the same precautions as are taken in the case of the pump-carcase to prolong the life of the material. In this respect it would, of course, be necessary for the designer to know the conditions and to have a rough analysis of the water which it was proposed to pump. No doubt practical engineers could render much assistance in this direction. The coat of varnish mentioned in the paper is not intended to meet conditions of this description. With regard to cost, a pumping set for a given output would certainly not be more expensive than for other types of machines now in use. I know of cases where the submersible motor-pump has been much lower in price in competition with other makers, particularly in the case of the single-stage sets described in the paper, and a very considerable saving in weight, space, and cost of material is obtained. I am quite confident that the submersible type of motor is much cheaper to build than a totally-enclosed machine of the same output.

The President mentioned the possibility of obstructions in the needle-valve, but I have never known an instance of this in the many hundreds of machines that have been installed, although some of these motor-pumps have been put to work on very rough jobs, even to the extent of pumping grain in solution. As a matter of fact, the water enters this valve at considerable pressure and velocity, and I think the more likely place to require attention is the filter. At this point provision is made for the blow-out cocks for an occasional sweeping of the space surrounding the filter.

Upon the question of reliability, I think it only necessary to add that an engineer in charge would feel more confident of his plant, knowing that water was always circulating through the windings, than to depend upon joints, glands, etc., in a totally-enclosed machine, which certainly might prove unreliable at a critical moment.

In reply to Mr. Tyson, the description of the three-core cable used for the 300-horsepower sets described in the paper is as follows:—

"Three-core armoured flexible cable 0·5 sq. in. section. Each core consists of 113 strands each of 70·029 tinned copper, making 791 wires in each conductor. Insulated one layer of pure and two layers of vulcanized indiarubber, double waterproof taped. Three of these cores laid up into a round cable, padded

circular with jute filling, double waterproof taped, heavily jute served and thoroughly compounded, armoured with one layer of 7/18 S.W.G. galvanized-iron strand.

" Double jute braided over armouring, and thoroughly compounded overall. Suitable for a working pressure of 440 volts."

With regard to the sealing-in of the cable at the coupling on the motor-frame, a further housing not shown on the drawing is used to clamp securely around the exterior of the cable and joint up to the top flange of the coupling; thus preventing the possibility of the entry of water round the armouring where clamped for earthing at the extreme end of the coupling.

In reply to Mr. Parkinson, the only additional particulars I can give of the special winding-cable is that the insulation consists of a special preparation of vulcanized rubber. The actual process of applying the insulation is known only to the makers of the cable.

I do not think the question of chafing in the slots as important, and I have never experienced any trouble in that connexion. The end windings are clamped to the frame of the machine, and it is at this point that the greatest vibration takes place. In addition to the clamping, the strands are all bound firmly together on the overhang.

The discussion of Mr. J. B. Sproston's paper on " Pit-head Baths " was closed.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM JULY 31ST TO SEPTEMBER 3RD, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
	July		14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	31	0	18′5	18′0	17′0	15′0	17′5	21′5	24′0	23′5	20′5	19′0	18′5	19′0	19′5
	August														
Mon. ..	1	0	18·5	18·0	15·5	14·0	16·5	21·5	22·5	21·5	19·5	19·5	19·5	18·5	19·0
Tues. ..	2	0	19·0	17·5	16·5	16·0	18·5	22·5	24·0	22·0	20·5	19·5	18·5	16·5	19·5
Wed. ..	3	1	18·5	19·0	17·0	17 5	25·0	29·5	29·0	24·0	18·5	18·0	19·0	19·0	21·0
Thur. ..	4	0	18·5	18·0	16·0	14·0	16·5	22·0	25·5	23·5	19·5	19·0	17·5	17·5	19·0
Fri. ..	5	1	14·5	15·0	16·0	15·0	21·0	24·5	25·5	23·5	20·0	17·0	18·0	19·5	19·0
Sat. ..	6	1	19·0	19·5	18·0	18·0	17·5	23·0	24·5	22·0	20·5	19·5	19·0	18·0	20·0
Sun. ..	7	1	18·5	17·0	15·5	15·5	19·5	22·0	24·0	21·5	19·0	18·0	18·0	18·5	19·0
Mon ..	8	0	17·5	19·0	17·0	13·5	16·5	20·5	23·0	23·0	19·5	19·5	19·0	17·5	19·0
Tues. ..	9	0	17·0	17·5	17·5	15·5	16·5	21·0	23·5	23·0	21·0	19·0	17·5	17·5	19·0
Wed. ..	10	0	15·0	16·5	18·0	15·0	15·0	19·0	22·5	22·0	20·0	19·0	19·0	19·0	18·5
Thur. ..	11	1	17·5	17·0	15·0	13·0	14·5	19·5	26·5	27·5	24·5	20·5	17 0	16·5	19·0
Fri. ..	12	1	17·5	15·5	15·0	14·5	16·5	21·5	25·0	23·0	19·5	19·0	18·5	17·5	18 5
Sat. ..	13	0	17·5	16·5	15·5	14·5	16·5	21·5	25·0	22·5	19·0	17·0	18·0	17·5	18·5
Sun. ..	14	0	16·0	15·5	14·5	13·5	16·5	21·0	23·0	21·0	18·5	18·5	16·5	18·0	18·0
Mon. ..	15	0	20 0	18·0	16·5	13·5	16·5	23·0	27·0	26·5	21·0	15·0	15·0	16·0	19 0
Tues. ..	16	0	19·0	17·5	15·5	14·5	16·5	22·5	25·5	23·5	21·5	15·5	17·0	17·0	19 0
Wed. ..	17	0	18·5	18·5	17·0	16·0	18·5	23·5	25·0	22·5	18·0	16·0	18·0	18 0	19 0
Thur. ..	18	0	18·5	18·5	16·0	14·5	18·0	24·0	25·5	22·0	18·5	17·5	18·5	19·0	19 0
Fri. ..	19	0	19·0	17·5	15·5	14·5	17·5	23·5	25·0	22·0	19·5	19·0	18·5	19·0	19·5
Sat. ..	20	0	18·5	17·0	16·0	14·5	17·5	23·0	25·0	23·5	20·0	18·5	16·5	17·5	19·0
Sun. ..	21	0	17·5	16·5	15·5	14·0	16·5	22·5	27·5	25·5	21 0	18·0	19·0	19·0	19·5
Mon. ..	22	0	18·0	17·5	17·0	15·5	17·0	22·0	25·5	24·5	20·5	18·0	18·5	18·5	19·5
Tues. ..	23	0	17·5	17·0	16·5	14·0	16·0	21·5	25·5	24·0	20·5	19·0	18·5	18·0	19·0
Wed. ..	24	0	17·5	17·5	16·5	14·5	16·5	21·0	25·0	23·5	20·5	19·0	18·0	18·0	19·0
Thur. ..	25	0	17·5	18·0	16·5	13·5	15·0	21·0	25·5	22·5	19·0	18·5	18·5	18·5	18·5
Fri. ..	26	0	18·0	16·5	15·5	16·0	16·0	20·5	24·0	27·0	24·0	20·0	19 5	18·0	19·5
Sat. ..	27	0	17·0	17·0	15·5	16·5	19·5	22·0	23·5	19·5	19·0	17 0	19·0	19·5	18·5
Sun ..	28	0	17·5	16 5	15·5	15·0	18·0	21 5	21·5	19·5	18·0	19·0	18·5	18·5	18·5
Mon. ..	29	0	17·0	16·0	15·5	14·5	16·5	21·0	21·0	18·0	17·5	19·0	19·0	18·5	18·0
Tues. ..	30	1	17·5	17 0	15·5	14·5	17·0	23·5	26·5	23·0	17·5	9·0	10·0	14·0	17·0
Wed. ..	31	1	14·0	16·5	17·0	16·0	18·5	21·5	24·0	22·0	18·0	17·5	17·5	18·5	18·5
	Sept.														
Thur. ..	1	0	18·5	17·5	17·0	15·5	17·5	21·5	22·5	20·5	18·5	18·0	17·5	14·5	18·0
Fri. ..	2	1	12·0	10·5	14·5	18·5	21·5	26·5	26·5	21·5	17·5	14·5	15·5	18·0	18·0
Sat. ..	3	0	18·0	17·5	16·5	15·5	17·5	21·5	22·5	20·0	18·5	19·0	17·5	16·5	18·5

Diurnal Inequality (i.e., departure from mean value for day).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
August, 1920	−2′·0	−2′·0	−2′·0	−2′·2	−3′·1	−3′·9	−4′·3	−3′·7	−2′·3	+0′·3	+3′·3	+5′·5
July, 1921	−1·3	−1·1	−1·5	−2·1	−3·1	−4·1	−4·5	−4·5	−3·4	−1·4	+1·4	+4·0
July, 1920	−1·6	−1·5	−2·0	−2·7	−3·8	−4·5	−5·1	−4·5	−3·2	−0·8	+2·0	+4·5

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
August, 1920	+6′·9	+6′·4	+4′·8	+2′·8	+1′·3	+0′·4	−0′·3	−0′·3	−0′·7	−1′·5	−2′·0	−1′·5
July, 1921	+6·0	+6·3	+5·4	+3·6	+2·3	+1·1	+0·4	+0·1	−0·6	−0·7	−1·0	−1·3
July, 1920	+5·9	+6·3	+5·7	+4·0	+2·4	+1·4	+0·4	+0·1	−0·2	−0·5	−1·0	−1·4

Mean Value for Month.

August, 1920.	July, 1921.	July, 1920.
14° 29′·3.	14° 19′·9.	14° 30′·5.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The above values were obtained from measurements made after "smoothing" the curves.

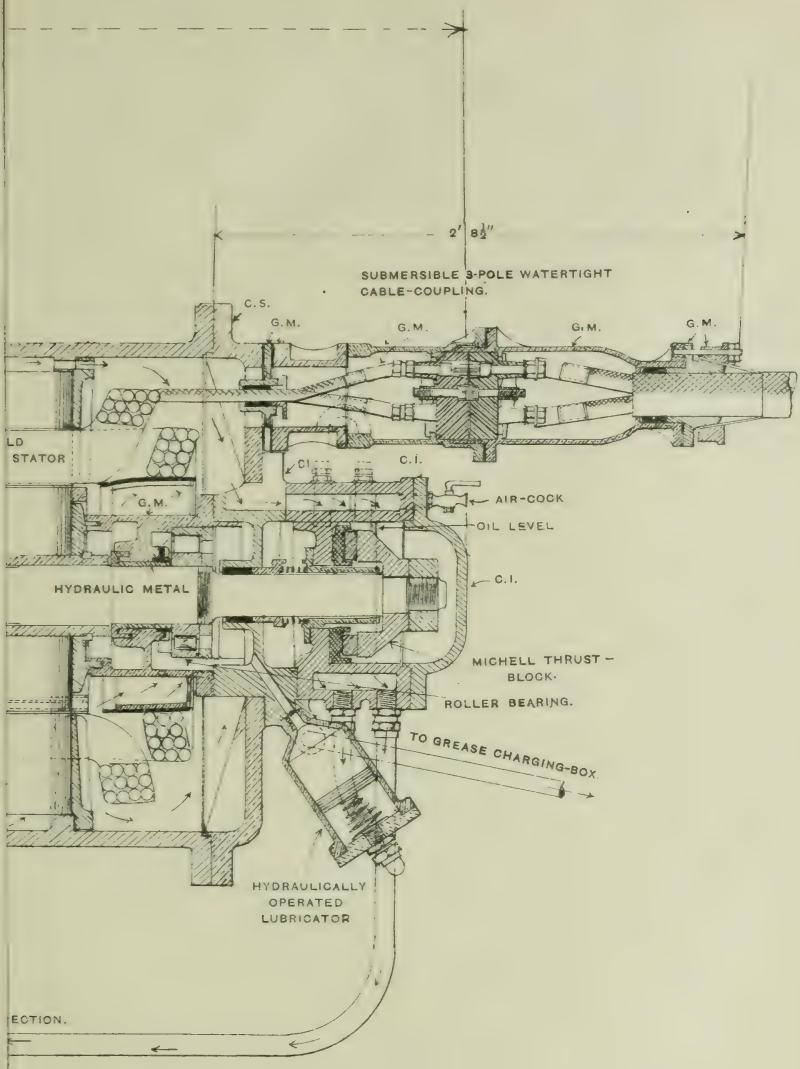


FIG. 4.—PLAN SHOWING OIL-CIRCULATION PIPES, WITH PROTECTION CAP FOR THRUST BEARING.

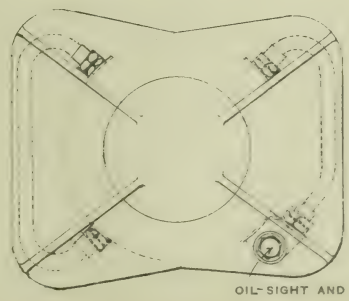
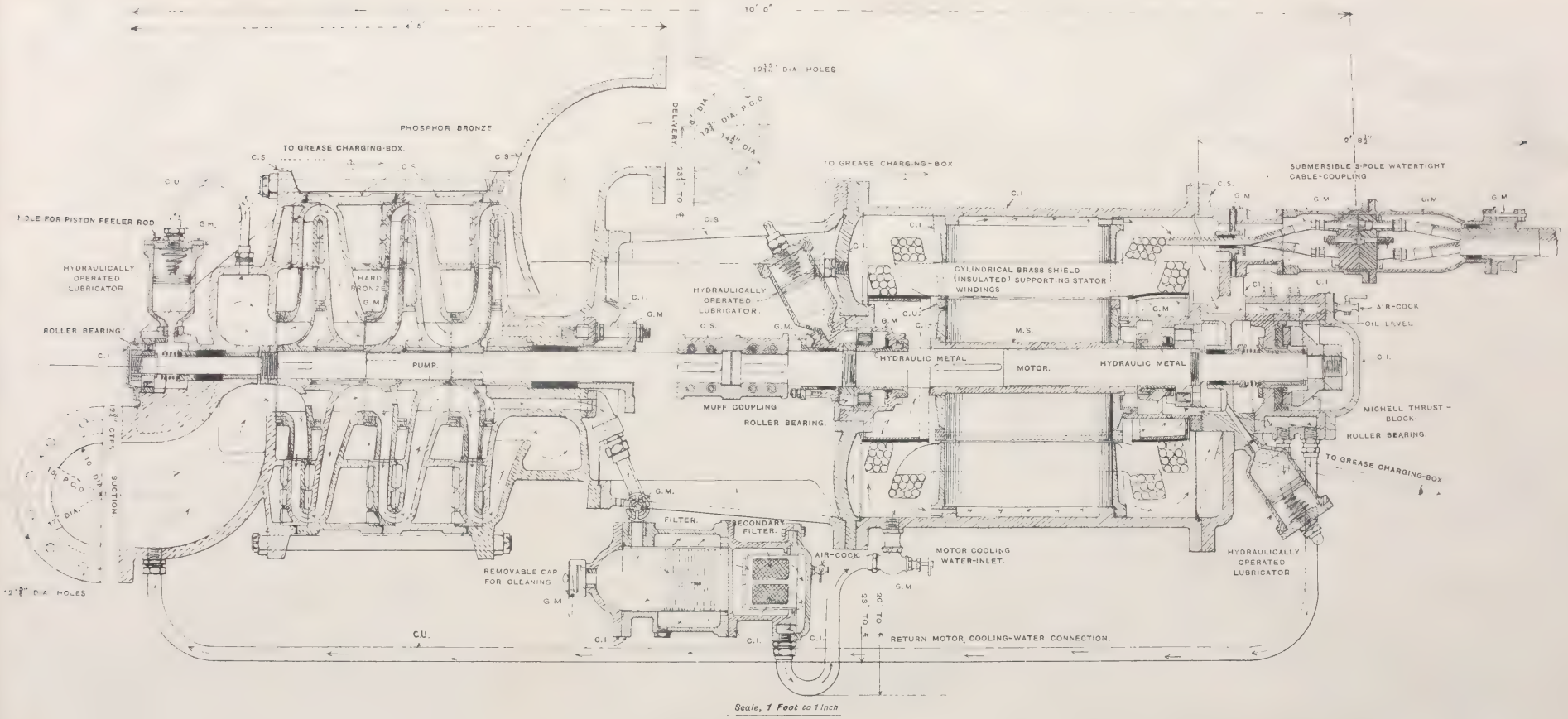


FIG. 1.—SECTIONAL ARRANGEMENT OF HIGH-LIFT SUBMERSIBLE MOTOR-PUMP.



Scale, 1 Foot to 1 Inch

FIG. 2.—SECTION OF GREASE-BOX FOR CHARGING LUBRICATORS.

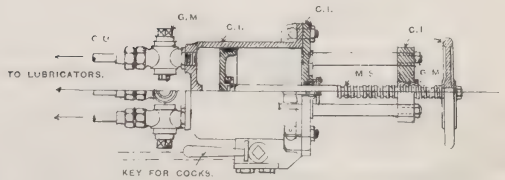
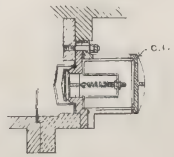


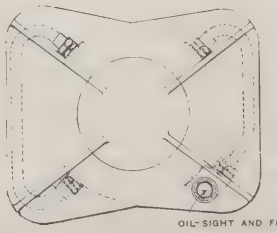
FIG. 3.—SECTION OF EMERGENCY AUTOMATIC VALVE.



Scale, 1 Foot to 1 Inch.

And^w Reid & Comp^y L^td Newcastle upon Tyne

FIG. 4.—PLAN SHOWING OIL-CIRCULATION PIPES, WITH PROTECTION CAP FOR THRUST BEARING.



OIL-SIGHT AND FILLER.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM SEPTEMBER 4TH TO OCTOBER 1ST, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	Sept. 4	1	17·5	19′·5	16′·0	15′·5	18′·5	22′·5	24′·5	22′·0	17′·5	17′·0	16′·5	15′·5	18′·5
Mon. ..	5	0	15·5	16·0	17·5	14·0	16·0	23·0	27·0	24·0	19·5	18·0	16·5	17·0	18·5
Tues. ..	6	0	17·5	18·5	16·5	15·5	14·5	20·0	25·0	24·0	20·0	18·5	16·0	16·5	18·5
Wed. ..	7	1	17·0	17·5	17·0	14·0	16·0	21·5	25·0	24·5	22·0	18·0	16·0	14·0	18·5
Thur. ..	8	1	12·0	8·0	15·0	15·0	17·0	20·5	22·5	22·5	20·5	18·5	18·0	15·5	17·0
Fri. ..	9	1	18·5	19·0	17·0	13·0	16·0	21·5	24·0	21·5	19·5	19·0	18·5	17·5	18·5
Sat. ..	10	0	17·0	17·0	16·0	14·0	16·5	22·0	23·5	20·5	19·0	18·0	18·0	17·5	18·0
Sun. ..	11	0	17·0	16·5	16·0	15·5	16·0	20·5	22·5	20·5	18·5	18·0	17·5	17·0	18·0
Mon. ..	12	0	17·0	17·0	16·0	15·0	15·5	18·5	21·5	20·5	18·0	17·5	17·0	17·0	17·5
Tues. ..	13	0	17·0	17·0	16·5	14·5	15·0	18·5	22·0	21·0	19·0	18·0	17·0	15·5	17·5
Wed. ..	14	0	16·0	17·0	16·5	14·0	13·5	19·0	23·5	22·0	19·0	18·0	17·5	17·5	18·0
Thur. ..	15	0	16·5	15·0	11·5	13·0	16·5	22·5	25·0	20·5	17·5	17·0	17·5	17·0	17·5
Fri. ..	16	1	16·0	16·0	16·0	15·0	16·5	21·5	23·0	21·0	18·5	18·0	14·5	15·0	17·5
Sat. ..	17	0	16·0	16·0	15·0	15·0	16·0	20·0	22·5	20·0	18·5	18·0	17·5	18·0	17·5
Sun. ..	18	0	17·5	17·0	16·5	15·0	17·0	21·5	23·5	22·0	20·0	18·0	14·5	16·0	18·0
Mon. ..	19	0	16·5	15·0	14·5	15·0	16·0	19·0	22·5	21·5	18·5	16·5	16·5	16·5	17·5
Tues. ..	20	0	17·0	17·0	16·0	13·5	14·0	19·5	24·5	22·0	18·5	17·5	17·0	16·5	18·0
Wed. ..	21	0	17·0	15·0	14·0	13·5	14·5	20·0	24·0	22·0	18·5	16·5	14·0	14·0	17·0
Thur. ..	22	0	14·0	15·5	15·5	14·0	14·0	18·0	20·5	19·5	18·0	17·0	16·5	16·5	16·5
Fri. ..	23	1	15·5	12·5	13·5	12·5	15·0	20·0	23·5	22·0	18·0	16·0	16·5	16·0	17·0
Sat. ..	24	0	16·5	16·0	16·0	14·5	13·5	16·5	20·5	20·5	17·5	17·0	16·5	16·5	16·5
Sun. ..	25	0	16·5	16·0	16·0	15·0	14·5	18·0	21·0	20·5	18·5	16·5	15·5	16·0	17·0
Mon. ..	26	0	16·5	16·0	15·5	13·5	14·0	19·0	21·5	20·5	17·5	16·0	16·0	16·0	17·0
Tues. ..	27	0	16·5	16·0	15·0	14·0	14·5	19·0	22·0	20·5	17·5	16·5	15·5	15·5	17·0
Wed. ..	28	2	16·5	15·5	15·0	13·5	13·5	18·0	23·0	23·5	21·0	15·5*	10·0*	8·0*	16·0
Thur. ..	29	2	11·5*	7·0*	12·5	13·0	15·0	20·5	23·0	20·0	15·5	8·5*	12·5	15·5	14·5
Fri. ..	30	1	17·5	17·0	16·0	15·5	15·5	19·0	20·5	18·0	16·5	15·5	15·5	15·5	17·0
Sat. ..	October 1	1	14·5	14·5	12·5	14·0	16·5	21·0	21·5	19·5	16·5	15·0	15·0	17·0	16·5

Diurnal Inequality (*i.e., departure from mean value for day*).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
September, 1920	−2′·3	−1′·7	−1′·9	−2′·4	−1′·9	−2′·0	−2′·4	−2′·6	−1′·8	+0′·5	+3′·3	+5′·5
August, 1921 ..	−1·3	−1·6	−1·6	−1·7	−2·8	−3·9	−4·3	−3·7	−1·6	+0·8	+3·4	+5·2
August, 1920	−2·0	−2·0	−2·0	−2·2	−3·1	−3·9	−4·3	−3·7	−2·3	+0·3	+3·3	+5·5

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
September, 1920	+6′·4	+5′·5	+4′·1	+2′·0	+0′·9	+0′·5	−0′·6	−0′·7	−1′·2	−2′·1	−3′·0	−2′·1
August, 1921	+6·1	+5·8	+4·1	+2·1	+1·0	−0·5	−1·1	−0·7	−0·9	−1·2	−0·9	−0·7
August, 1920	+6·9	+6·4	+4·8	+2·8	+1·3	+0·4	−0·3	−0·3	−0·7	−1·5	−2·0	−1·5

* Large disturbances during this interval.

Mean Value for Month.

September, 1920.	August, 1921.	August, 1920.
14° 28′·7.	14° 19′·0.	14° 29′·3.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The normal value for an hour is the mean declination for that hour in the month, derived from quiet days only, or from all days excluding those of character "2." On a day of character "0" declination at any hour will usually be within about 3′ of the normal. On a day of character "1" the departure from the normal will usually not exceed 5′, but it may occasionally be as much as 10′, or even more. On a day of character "2" the departure from the normal will seldom exceed 20′, but departures of 30′, or even on extreme occasions of 1° or more, may occur.

The above values were obtained from measurements made after "smoothing" the curves.

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Explanations.

The — at the beginning of a line denotes the repetition of a word or words followed by a comma in the preceding entry; and in the case of Names, it includes both the Christian Name and the Surname; or, in the case of the name of any Firm, Association, or Institution, the full name of such Firm, etc.

Discussions are printed in *italics*.

The following contractions are used :—

M. C.—The Midland Counties Institution of Engineers.

M. G.—The Manchester Geological and Mining Society.

M. I.—The Midland Institute of Mining, Civil, and Mechanical Engineers.

N. E.—The North of England Institute of Mining and Mechanical Engineers.

N. S.—The North Staffordshire Institute of Mining Engineers.

S. I.—The Mining Institute of Scotland.

S. S.—The South Staffordshire and Warwickshire Institute of Mining Engineers.

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PROFESSOR SIR JOHN CADMAN, K.C.M.G., D.Sc.

PRESIDENT OF THE INSTITUTION OF MINING ENGINEERS.

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THE INSTITUTION OF MINING ENGINEERS.

ESTABLISHED JULY 1ST, 1889; INCORPORATED BY ROYAL CHARTER FEBRUARY 9TH, 1915.

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Mr. William H. Telfer, Birkenshaw, Uddingston, Lanarkshire.
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Mr. R. L. Weeks, Willington, Co. Durham.
*2nd-Lt. Noah T. Williams, B.Sc., Queen's Chambers, 5, John Dalton Street, Manchester.
Mr. William Williamson, Sherborne, South Park Road, Hamilton.
Mr. William Brumwell Wilson, 19, West Parade, Newcastle-upon-Tyne. (*Deceased.*)
Mr. Ernest Seymour Wood, M.Inst.C.E., The Cottage, Bath Terrace, Gosforth, Newcastle-upon-Tyne.

* Members of Finance and Publications Committee.
† Chairman of Finance and Publications Committee.

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Messrs. John G. Benson & Sons, 27, Grey Street, Newcastle-upon-Tyne.

Treasurer.

Mr. Charles Catterall Leach, Seghill Hall, Northumberland.

Honorary Foreign Secretary.

Prof. Henry Louis, M.A., D.Sc., A.R.S.M., M.Inst.C.E., F.I.C., 4, Osborne Terrace, Newcastle-upon-Tyne.

Secretary.

Mr. C. McDermid, Cleveland House, 225, City Road, London, E.C. 1.

622.06

TRANSACTIONS

OF

THE INSTITUTION

OF

MINING ENGINEERS.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

ANNUAL GENERAL MEETING,

HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE, AUGUST 6TH, 1921.

LT.-COL. F. R. SIMPSON, RETIRING-PRESIDENT, IN THE CHAIR.

Mr. Charles Catterall Leach was unanimously elected President for the ensuing year.

ABSTRACT OF ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

The Council is pleased to report a net increase of 62 in the membership, the total number on the roll now being 1,246, as against 1,184 for the preceding year. The Institute has lost 84 members by death, resignation, etc., including Sir Lindsay Wood, Bart., who was elected a member in 1857, was first elected to the Council in 1863, was Vice-President in 1869, and was President from 1875 to 1878 and from 1902 to 1903. He was also President of The Institution of Mining Engineers for the years 1896-1897 and 1902-1903. Mr. W. O. Tate, a member of the Council, also died during the past year.

The additions to the Library by donations, exchange, and purchase include 92 bound volumes and 12 pamphlets, reports, etc.; and the Library now contains about 16,128 volumes and 600 unbound pamphlets.

Prizes have been awarded to the writers of the following papers, communicated to the members during the year 1920-1921 :—

"The Electric Welding of a Corroded Boiler-shell," by Mr. Arthur Kenneth Dawson, Assoc.I.M.E.

"Steam Economy," by Mr. Philip Kirkup, Junr., Assoc.I.M.E.

"The Production and Transmission of Compressed air in Mines," by Mr. John Thomas Pringle, Assoc.I.M.E.

The Associates and Students' Section has been revived, and several meetings have been held for the reading and discussion of papers. An excursion was made to the rope works of Messrs. Joseph Crawhall & Sons, Gateshead.

The North of England Institute of Mining and Mechanical Engineers: Abstract of Balance-sheet, June 30th, 1921.

Liabilities.	£	s.	d.
Subscriptions paid in advance	73	1	0
G. C. Greenwell prize fund (balance)	29	16	2
Balance, being capital, exclusive of the asset Wood Memorial Hall	22,642	2	5
	£22,744	19	8

Assets.	£	s.	d.
Cash at bankers and in hand	1,346	13	11
Subscriptions outstanding	354	9	0
Investments	9,177	11	2
Books, pictures, *Transactions* and other publications ...	11,866	5	7
	£22,744	19	8

Abstract of Income-and-Expenditure Account for the Year ended June 30th, 1921.

Expenditure.	£	s.	d.
To The Institution of Mining Engineers	1,589	0	8
,, Salaries	751	10	0
,, Office rent, cleaning, etc., ...	568	11	8
,, Printing, stationery, library books, etc.	347	10	6
,, Postages and incidentals	257	16	6
,, Travelling expenses	31	7	5
,, Prizes	3	3	0
,, Balance, surplus on the year	665	6	6
	£4,214	6	3

Income.	£	s.	d.
By Subscriptions and donation received	3,617	16	0
,, Income from investments	446	11	6
,, *Transactions* sold	13	18	0
,, Income-tax refunded	136	0	9
	£4,214	6	3

We have examined the above balance-sheet with the books, vouchers, and securities relating thereto, and certify that, in our opinion, it is correct. We have accepted the assets "Books, pictures, *Transactions* and other publications" as valued by your officials.

Newcastle-upon-Tyne,
August 5th, 1921.

JOHN G. BENSON & SONS,
Chartered Accountants.

As shown by the subjoined abstract of accounts, the total receipts, including £136 0s. 9d. received for the return of income-tax for the year ending April 5th, 1921, amounted to £4,214 6s. 3d. The expenditure was £3,548 19s. 9d., as against £2,793 3s. 9d. in the previous year.

The balance of income over expenditure is £665 6s. 6d., and adding to this the balance of £681 7s. 5d. from the previous year, the sum of £1,346 13s. 11d. remains to be carried forward.

The Annual Report and Accounts were adopted.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated :—

MEMBERS—

Mr. RISAKU ATSUMI, Mining Engineer, Tagawa Colliery No. 3, Ita-machi, Fukuoka-ken, Japan.

Mr. JOHAN BÖLGER, Mechanical and Electrical Engineer, Messrs. F. Kloos and Sons, Kinderlijk, Holland.

Sir JOHN FRANKLAND PAYNE GALLWEY, Bart., Managing Director, 58, Victoria Street, Westminster, London, S.W. 1.

Mr. WILLIAM WAINWRIGHT, H.M. Inspector of Mines, West View, Field-house Lane, Durham.

Mr. CHRISTOPHER WILKINSON, Colliery Manager, Fern Royd, Gilesgate, Durham.

ASSOCIATES—

Mr. JAMES JOHNSON, Chargeman, 33, Luke Street, Trimdon Grange, Co. Durham.

Mr. JAMES KING, Back-overman, Broadheath, Southwick, Sunderland.

Mr. THOMAS MORDUE, Colliery Under-manager, 1, Front Street, Trimdon Grange, Co. Durham.

Mr. ALEXANDER RANKIN, Colliery Under-manager, Ingleside, Blaydon Burn, Blaydon-upon-Tyne, Co. Durham.

STUDENT—

Mr. ALFRED MOORE, Mining Student, 3, Headlam Street, Byker, Newcastle-upon-Tyne.

PRESIDENTIAL ADDRESS.

BY LT.-COL. F. R. SIMPSON.

I feel it a great honour to have been President of this historic Institute for the past two years, and, as my term of office has come to an end, I wish to say a few words before formally retiring in favour of the newly-elected President.

During the past two years all who have been connected with the management of collieries have had an anxious time, and it was quite impossible for me to compile the customary Address at the time of my election to the Presidency. The coal industry is now, however, recovering from some of its troubles, and I hope that the future will show increasing confidence between employers and employed, which, in my opinion, is the solution of many of our difficulties, and will allow mining

engineers to give their full attention to purely mining questions apart from those of wages, which have taken up so much valuable time in the past.

With regard to the general working of the Institute during my years of office, the Council has successfully re-established the Associates and Students' Section, the members of which have produced several good papers, and have also held excursions that have been largely attended. It is perhaps unnecessary for me to urge the great importance of encouraging the younger members, more particularly as so many suspended their professional studies to serve their country during the war. I think it is generally admitted that the writing of papers, however elementary, and the replying to the subsequent discussion, are most valuable as a means of acquiring and conveying technical knowledge. In my opinion the Council should continue its special efforts to stimulate the interests of the younger members, who will eventually be responsible for the successful conduct of the mining industry.

I wish to announce, among other changes of note which have been made, that Mr. M. W. Parrington has intimated his desire to be relieved of the responsibilities attached to the duties of Honorary Secretary, and the Council has appointed Prof. Henry Louis as his successor. The Council considers that it has been extremely fortunate in having had the benefit of Mr. Parrington's gratuitous services, and fully realizes its debt of gratitude to him for occupying that important post during a time of stress and anxiety owing to the war and its effects.

There has been another change which largely affects the Institute, namely, the decision of the Council of The Institution of Mining Engineers to join with The Institution of Mining and Metallurgy for the purposes of office and library accommodation in London, and also for the more efficient management of the interests of the two bodies concerned by the appointment of a joint Secretary. Up to the present time these two Institutions have worked on separate lines, one devoting itself entirely to metal-mining and the other to coal-mining. The new arrangement in no way affects the individuality of the two Institutions, nor does it interfere with the continuance of the pursuit of the objects for which they were originally founded. In these days it is desirable that mining engineers of all descriptions should be in a position to express opinions or give advice on matters of national importance relating to mining, and the co-operation of the two branches of mining, employing one Secretary, will add very much greater weight to any opinion which may be expressed than was the case in the past. Personally, I have every confidence that the change in policy will considerably advance the status and prestige of both Institutions.

I wish on this occasion to touch on a few points in connexion with the use of percussive coal-cutting machines, which I hope will be of interest to many of the members in their endeavours to increase the output of coal per person employed in bord-and-pillar working. During the last twenty years serious efforts have been made to increase the output per shift per person employed—principally in the direction of the performance of the more arduous part of coal-getting by machinery driven by electricity or compressed air. In the North of England the nature of the strata admits of the formation of pillars of coal that can be left for the support of buildings or areas of land, and in that system of working a large number of percussive coal-cutters have been introduced. It is unfortunate that those machines have not yet been successfully adapted for direct driving by electricity, and that

compressed air, with its low efficiency, has to be used. The following remarks on coal-cutting are confined to what is locally known as "whole" work—that is, the formation of pillars of coal. This system of working is of considerable importance to many of us who have large areas in which pillars of coal have to be left for the support of buildings on the surface. Unless such areas can be economically worked, a large quantity of coal will be lost.

Speaking broadly, there are two methods of supplying compressed air to percussive coal-cutting machines: (1) air compressed at the surface and carried by pipes to the face; and (2) air compressed by electrically-driven plant as near the face as possible. Both systems have their disadvantages: the first in the losses due to great lengths of pipes, and the second in the losses attending the conversion of electricity into compressed air. I do not propose to discuss the disadvantages of the systems, but simply to emphasize the fact that they both lack efficiency.

With regard to coal-cutting, I think that it will be granted by practical men that, so far as the actual undercutting is concerned, there is no great difficulty apart from the inefficient use of power; but the whole success depends upon the speedy "flitting" of the machines, the efficient filling away of the coal, and its transport from the face to the main haulage. In those difficulties I include the fixing of economic piece prices for the performance of the work. If the output per person employed can be increased by coal-cutting machinery to such an extent as to cover the interest on capital expenditure, cost of upkeep, and running of machinery, well and good; but, if not, the only benefit obtained is the relief of the more arduous work of the coal-getter. That, of course, is much to be desired, and is heartily welcomed by all of us; but economic results can be realized only when the coal-getter recognizes the amount of arduous work which he has been saved, and that his best interests lie in the highest possible production. By machinery the coal-getter is relieved of undercutting, which is most strenuous work performed in an uncomfortable position; and where conveyors are used he is relieved of the casting of coal, which is also a difficult operation in thin seams. The adoption of machinery can be successful only where the management has carefully systemized the work and provided efficient transport for the coal produced, and where the coal-getter recognizes the elimination of the most arduous work by putting the same energy into the more pleasant form of work that remains in breaking down and filling away the coal. It is most difficult to obtain a fair comparison between manual and mechanical operations, but I have taken out costs in a district of a seam 3 feet 9 inches thick where pillars are being formed at the same time by hand-hewing and by percussive machines. The conditions of work are rather in favour of hand-hewing, as the places are rising and dipping where the machines are working, but they are sufficiently equal to allow of a comparison being made during a period of four weeks in November, 1918.

The basis cost for hand-hewing was 2s. 3·60d. per ton, and for machine-mining 3s. 8·02d., leaving a difference of 1s. 4d. in favour of hand-hewing. The cost of labour alone is practically equal to the cost of hand-hewing, without making any provision for capital expenditure, materials, or power. I have a detailed statement of costs, which I propose to reserve for a future meeting, in the hope that the subject may be considered worthy of further discussion.

The results which I have given may be open to criticism, to which I shall be pleased to submit, if it will indicate the way to improvement.

We are inundated with figures showing the results of trials of various machines; but if members would lay before the Institute particulars of working over a considerable period, I am sure that they would greatly assist the economic development of this important branch of mining. I do not for one moment wish to imply that I am opposed to the adoption of coal-cutting machinery, but merely to show the necessity of a thorough investigation, with a view to overcoming existing defects.

The coal-cutting plant in question was intended for the working of a large area of coal, 2 feet 4 inches thick, under a number of buildings, for the support of which it is necessary to leave pillars, on the assumption that it would be quite impossible to work the coal profitably by hand-labour. When, however, the demand for coal became urgent, the machines were put into the thicker seam, to which the costs referred to relate, and it was naturally expected that, with the large yield per square foot undercut in a seam of 3 feet 9 inches, the results would be in favour of machine-mining.

Although the result in this particular instance, so far as actual costs are concerned, is in favour of hand-hewing, there are many distinct advantages in machine-mining, which should be taken into account, such as regularity of output, which is not affected by the daily variations in the hardness of the coal, nor by the difference in the individual capacity of the coal-getter. There is also the advantage of being able to push forward winning-places which, in practice, often happen to be occupied by indifferent coal-getters. The benefit of securing a large output from a given area should not be overlooked, nor the fact that the machine-man can be more quickly trained than a hand-hewer. There is also the advantage of a higher yield of large coal. The prevalence of the longwall method has, to a great extent, caused the working of "whole" work to become a lost art, and, despite the somewhat disappointing figures, machine-cutting in thin seams which have, for various reasons, to be worked in that way is almost a necessity. There are many instances, of course, where thin seams can not be worked by hand, and many others where machinery is adopted without any expectation of an increase of output, but rather as an insurance against a decrease in the yield per person. There are numerous advantages in machine-mining which will occur to members, and of which I will be greatly interested to hear.

In accordance with the figures I have given, it would appear that in a seam 3 feet 9 inches in thickness, worked by the bord-and-pillar system, where a hewer produces 2·18 tons per shift, it is unprofitable to adopt machinery unless other advantages can be obtained which are worth 1s. 5d. per ton. That matter seems to me to be of sufficient importance to warrant the Institute reinstating a Committee for the systematic investigation of all types of coal-cutting and conveying machinery, and the publication of a report on the same lines as that of the previous *Report of the Committee upon Mechanical Coal-cutting*, published in 1905, which was of such great value to the mining industry.

I would like to allude briefly to the many expressions of opinion by persons technically ignorant of coal-mines and their difficulties, to the effect that more up-to-date methods and more machinery are required in British mines. It is quite incorrect, however, to think that all mining can be economically carried out by means of machinery, as the conditions vary so greatly, and in many cases machinery cannot be applied. With regard to the general use of machinery in mining, I venture to say that, with few exceptions, the British mines are well equipped in every

way, and they have certainly been the pioneers in coal-cutting and conveying, whilst full advantage has been taken of the use of electricity and compressed air for the transmission of power. It is true that some of the collieries are somewhat lacking in architectural beauty, so far as the buildings at the surface are concerned, but that defect has seldom interfered with the efficiency of the plant. It should be understood, when comparing the surface arrangements of some of the older collieries with those of other countries, that their engineers, generally, had the advantage of viewing a number of our own collieries and of being able to select the best ideas from each. If, however, we compare a British modern colliery with those of any other country, we need not fear the result. I am confident that the underground lay-out in regard to ventilation, haulage, and coal-cutting is, at any rate, equal to that of any other nation.

With respect to safety statistics, it can be shown that the death-rate per person employed in our mines compares favourably with that of other countries. As to our methods, they have been universally adopted for their safety and economy, and as to results I can only refer to the steady increase in output during the pre-war ten years, which increased from 230,324,295 tons in 1903 to 287,411,869 tons in 1913. The present plant at British collieries is capable of dealing at least with the output obtained in the year 1913, if markets could be found for its disposal.

In conclusion, I gratefully acknowledge my indebtedness to the Council and staff of the Institute during my two years of office. I congratulate you on electing Mr. Leach as President for the ensuing year. In Mr. Leach we have a mining engineer who has taken the deepest interest in the Institute, and I feel sure that his year of office will be one in accordance with the highest traditions of the Institute.

Col. W. C. Blackett, C.B.E. (Sacriston): I beg to move a vote of thanks to the President for his excellent Address, which gives food for much thought. There is doubtless a great tendency amongst certain people to extol the merits of machinery beyond what it really deserves. We are constantly being held up before other countries—one in particular with whose natural advantages we cannot hope to compete. I am very glad, personally, that Col. Simpson has directed attention to a subject which has been considerably neglected.

Mr. C. C. Leach (Seghill): I have pleasure in seconding the vote. Col. Simpson's family has been in the coal industry all my life and before that. No family has done more to advance the interests of the coal-trade generally. I appreciate that he will be a difficult President to follow.

The President: I thank you very much for the kind way in which you have received my remarks. I felt rather diffident in giving the figures relating to the two methods of working, and the fact that there is a difference of 1s. 4d. makes one think hard. These figures are startling, and I hope they will be of benefit to those with similar problems.

HONORARY SECRETARY.

The PRESIDENT (Lt.-Col. F. Simpson): I wish to move a vote of thanks to Mr. Parrington for the manner in which he has carried out the duties of Honorary Secretary during the past few years. Mr. Parrington felt he could not give to the work in hand the attention which he wished, and he intimated that he would like to be relieved of the post. He stepped into the breach at a critical and serious time, and I propose that a resolution expressing our thanks to him and our appreciation of the services rendered to us be passed by the meeting. I formally move that the best thanks of the Institute be sent him for his services during the past few years.

Mr. C. C. LEACH seconded, and the resolution was carried by acclamation.

The newly-elected PRESIDENT (Mr. C. C. Leach), in taking the chair, said: You have done me a very great honour this day in electing me President. When I look across the room to the portraits of my predecessors, I realize to what a very responsible position I have attained. The Institute was founded for the purpose of safeguarding life and property, and when I commenced my mining career that was one of the objects that drew me to it. I appreciate the kind words of the Retiring-President. I can only say that I will do my best to further the interests of the Institute with the assistance of the Council and members. If members would look back into the *Transactions* of the Institute, they would realize the great amount of good work that has been achieved by the Institute in making investigations which have led to the pits being made safer and more comfortable.

I am very glad to see that we have recently come into intimate association with The Institution of Mining and Metallurgy, as there are many matters which affect both societies, and it is to our advantage that they should be connected. I believe that if the miners and others realized the efforts and achievements in mining due to the Institute's work, many of the statements made against its members would not be entertained so readily as they appear to have been. The Institute is really a Welfare Institute. That seems to be what the Government is now wanting, and it has insisted upon the coal-trade contributing towards welfare projects for the men. The Institute has been doing welfare work all its life—and doing it without any Government assistance, as it has always wished to be free from all outside influence.

THE CARBONIZATION OF COAL AT LOW TEMPERATURE.

By JOHN ROBERTS, D.I.C.

I.—Introduction.

Carbonization Temperature.—The temperature at which the carbonization of coal is carried out depends on the nature of the products required, and will vary from 450° to 1,000° Cent., or more. In gas-works practice, where the main object is the production of gas, the temperature in the flues may exceed 1,200° Cent., and this temperature is also employed in coke-oven practice, where hard metallurgical coke is the chief product. In the manufacture of coalite or semi-coke, where the chief aims are the production of a smokeless fuel and the recovery of oils from coal, the range of temperature may be from 450° to 750° Cent. Where this range is employed, the process is known as "low-temperature carbonization," although, perhaps, the term "low temperature" should be restricted to temperatures varying from 450° to 600° Cent., and the term "intermediate temperature" applied if carbonization is carried out between 600° and 750° Cent. As, however, certain so-called low-temperature systems employ the latter temperature, it will be regarded in these notes as the upper limit of low-temperature carbonization.

Coal-carbonization at low temperature may be said to date from the year 1906, when Mr. T. Parker took out his patent (British Patent No. 14,365, 1906) for distilling bituminous coal for the production of smokeless fuel. The temperature at which he proposed carbonizing was about 800° Fahr. (about 430° Cent.). The product obtained at this temperature more closely resembled coal than coke—hence the term "coalite." The fuel now produced by Parker's successors more nearly resembles coke than coal, and would more appropriately be termed "cokeite" or semi-coke. Under certain conditions, however, as will be shown later, a fuel devoid of the characteristics of coke or of semi-coke may be made from coking coals at 750° Cent.

Semi-coke.—It is not proposed to discuss the economic aspect of low-temperature carbonization in these remarks, as the subject has been emphasized over and over again by interested parties, most of whom are rightly concerned about the enormous waste resulting from present-day methods of utilizing coal, particularly for domestic purposes, and who also appreciate the increased demand for liquid fuels obtainable from coal. Unfortunately, up to the present no process has been evolved for the production of semi-coke in bulk that can be recommended to investors as a commercial proposition. In order to avoid misunderstanding, it should be stated that by production in bulk is meant carbonization on a scale comparable with coke-oven practice—that is to say, with units capable of turning out (say) 500 tons of semi-coke per day. Plants are in existence which produce excellent semi-coke, but it is doubtful whether the operators would undertake contracts to deliver a tenth of the above daily output.

Properly-manufactured semi-coke which has been carbonized at a temperature between 600° and 750° Cent. is an excellent fuel. When

produced from an average coking coal, it would contain from 6 to 12 per cent. of volatile matter, which would render it readily ignitable in an ordinary open grate. It is absolutely smokeless, but burns with a flame resembling that from a producer-gas until the volatile matter is all driven off. It gives a very bright-red glow and evolves great heat. In this connexion it may be well to quote the results obtained by Dr. Margaret White Fishenden.* Mention is made on pages vi, 41, 42, and 69 of her Report of the increased radiant efficiency of semi-coke over that of coke, coal, or anthracite; and the following extract is from page 69 :—

"Low temperature carbonization cokes were remarkably efficient as radiating sources, two samples giving, when dry, respectively, 34 and 31 per cent. radiant efficiency as compared with 24 per cent. for coal in the same grate. The calorific value of these fuels was about 13,200 B.Th.U. per lb., and the radiation emitted was therefore some 25 per cent. in excess of that produced from an equal weight of coal of calorific value 14,500 B.Th.U. per lb. As in the case of coke, the radiant efficiency of course diminished as the moisture content of the fuel increased, but for the highest proportions of water found (11 per cent. by weight) the aggregate radiation emitted was still considerably in excess of that thrown out by an equal weight of coal. The fires made from these fuels were bright and pleasant and were free from both smoke and smell; they were lighted easily by the usual methods, and without the addition of any coal."

Other figures quoted in the Report (page 41) show that in some cases the excess radiant efficiency over that of coal was 30 per cent. The suggested explanation for these results is "the peculiar structure of these fuels, in which, owing to their porous nature, the area of exposed surface is large" (page 42).

Those who have used this fuel will agree readily with Dr. Fishenden as to the increased radiant heat obtainable from semi-coke. It should be pointed out, however, that this fuel should not be used in conjunction with coal, but should be employed alone. Neither should paraffin be used to hasten ignition, as the hydrocarbons become decomposed, deposit carbon in the pores of the semi-coke, and thus increase the difficulty of ignition.

The fuel is a most desirable one for domestic and certain other purposes, and every encouragement should be given to investigators whose aim is the solution of the problems connected with its manufacture.

II.—Low-temperature Difficulties.

(*a*) *Expansion of Coals.*

Effect of Heat on Coal.—It will be obvious to anyone acquainted with the behaviour of coals on heating at low temperatures, as above defined, that the first difficulty to be overcome is that due to the expansion of coals, and the lower the working temperature the greater is the difficulty. Parker soon realized this, and his first retort (British Patent No. 4,067, 1907) was tapered to facilitate discharging. He regarded the problem as a mechanical one, which was probably the correct view where the working temperature was 430° Cent. Nowadays, higher temperatures are employed, and the problem, as will be shown later, is not a mechanical one, but may be solved by physical or chemical means.

When fine coal is carbonized, the first stage in the process is the

* *The Coal Fire*, Fuel Research Board, Special Report No. 3.

melting of the binding-material, which takes place at temperatures ranging between 350° and 450° Cent., depending on the nature of the coal. The binder in the coal fuses and cements the mass. An average caking coal contains more binder than is required for this purpose, and the continued application of heat causes the decomposition of this surplus binder, with the consequent expansion of the coal. Fig. 1 will serve to demonstrate this point. This photograph shows part of a charge of 200 grammes of coking coal that has been heated in a fireclay crucible over a Bunsen burner. A thermometer in the centre of the charge indicated when the temperature thereat reached 360° Cent., at which stage the crucible was withdrawn and allowed to cool. The unfused coal was removed before taking the photograph. The zone marked (*A*) is the "fusion zone," which is compact and travels in advance of the highly porous "decomposition zone" (*B*). Here the excess binder has been

FIG. 1.—SHOWING CARBONIZATION ZONES: (*A*) FUSION ZONE; (*B*) DECOMPOSITION ZONE; (*C*) SEMI-COKE ZONE; AND (*D*) HIGH-TEMPERATURE COKE ZONE.

decomposed, producing a highly-cellular structure and causing the mass to swell considerably. Below this zone is a layer of semi-coke (*C*), in which the cells are much smaller than at (*B*), but the "semi-coke zone" is still less dense than the "high-temperature coke zone" (*D*). Between (*C*) and (*D*) there was observed an iridescent zone, which will, for convenience, be called a "rainbow zone," on account of the prismatic colour effects.

Secondary Contraction at High Temperatures.—As the heat was applied from below and travelled upwards, it is obvious that (*D*) passed through all the stages, and that there has been a *secondary contraction* of the semi-coke as it became converted into coke. This has been further demonstrated by coking two charges of the same coal in iron cylinders 28·5 millimetres in diameter and 24·5 millimetres in depth. The same quantity of coal was used in each cylinder, and both were heated side by

side in an electric furnace, the temperature of which was gradually raised from 450° Cent. at the commencement to 750° Cent. after one hour and 40 minutes. One charge was then withdrawn and the temperature raised to 900° Cent. during the succeeding 50 minutes, after which the second charge was withdrawn. The diameter of the coke cylinder from the crucible first withdrawn was found to be 26·8 millimetres, while that of the second was 25 millimetres, showing that a secondary contraction had taken place.

It will be seen, therefore, that in low-temperature work expansion has to be specially provided against. If carbonization is carried out at about 430° Cent., the resulting coalite will be highly cellular and soft, and will stick to the sides of the retort even more tenaceously than where intermediate temperatures are employed. In coke-oven practice the secondary contraction causes the coke to leave the sides of the retort, and it is thus readily discharged by means of a ram. It also tends to produce cracks in the coke.

Relation of Volatile Matter to Expansion.—Coals possessing no excess binder will not expand on heating. One or two Yorkshire coals, such as the Brodsworth Top Softs, possess only just enough binder to cement the mass, and actually contract on heating. A coal from the neighbourhood of Chesterfield also behaves in a similar manner. These coals when freshly mined appear to be eminently suitable for low-temperature work. On their being heated over a Bunsen burner in the manner previously described, the coke and semi-coke are almost identical in texture. In these cases, the volatile content is practically the same as that of other Yorkshire coals which show considerable expansion. In the case of Welsh coals, those having comparatively high volatile-content like the Elled, Big Rock, and No. 2 Rhondda expand much more than the low-volatile coals like the Gellideg, Red Vein, Lower Five Feet, and seams from the Neath area. On the other hand, certain Kent coals of volatile-content equal to that of the Big Rock expand much more than any of the principal Welsh and Yorkshire seams.

Except in limited areas, the percentage of volatile matter in a coal does not determine its suitability for low-temperature work. In the South Wales Coalfield, as is well known, progressive anthracitization has taken place from east to west, resulting, in my opinion, in a loss of volatile matter and in the destruction or partial destruction of the binding-material.

(*b*) *Prevention of Expansion.*

Separation of Expanding Constituents in Coals.—Several mechanical devices, some of which are ingenious, have been invented for taking up the expansion of coals, but as I am of opinion that the problem is a physical and chemical one, I do not propose to describe these appliances, which have recently been dealt with elsewhere.

Messrs. Beet and Findley* suggested using branded coals and separating the dull coal (durain) from the bright coal (clarain) by a process of washing, in which liquids of various specific gravities would be used. Dull coal does not expand on heating; hence it was proposed to utilize this fraction for low-temperature work and reserve the bright coal for making high-temperature coke. It is obvious, however, that the washing process would be a delicate operation, and would add considerably to

* "The Better Utilization of Coking Slack," *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 213.

the cost of carbonization, unless some simple process could be devised to accomplish this object. They also assumed that, on account of the strong caking properties of clarain, a harder and denser metallurgical coke could be obtained from this product than by using the raw coal as mined. My own experiments lead me to oppose that view. It does not necessarily follow that the higher the coking index of a coal the denser and harder will be the product. On the contrary, the density, hardness, toughness, and crushing strength of cokes can be generally increased by the additon of inert matter, as will be now explained.

Method of Dealing with Swelling Coals.—The swelling of coals has been shown to be due to the presence in them of excess binder; therefore, two remedies will suggest themselves, only one of which will be named at this stage—the binder may be employed to bind inert material. Curiously enough, this remedy had been patented long before the birth of low-temperature carbonization, although it was not suggested to apply it for the purpose now proposed. The process consists in mixing inert carbonaceous matter, such as coke-breeze, with the coal before charging it into the retort. In 1859, M. Joseph Souquière, of Paris, described "A New or Improved Process for Distilling Coal" (British Patent No. 1,091, 1859). The description of the process contains the following:—

"The method of agglomeration comprised in this improved arrangement consists in pulverizing the coke produced by any of the known processes and mixing it with various proportions of pounded coal of the same or different kind as that from which the coke has been produced. This mixture is then heated either in the distilling apparatus used for making the coke originally, or in a separate apparatus, and thus new coke is obtained, composed of one part coke twice distilled, and another part coke which has been once distilled; the coke twice distilled being always of greater density than that only once treated. Further, this improved coke does not present a spongy appearance; it is also sonorous and firm, and suitable for all purposes, hence its commercial value is incontestably superior to that of the coke prepared by known processes. From the foregoing, it will be understood that the proportions of coke and coal forming the mixture may vary according to the nature of the coal and the quality of the coke desired to be obtained."

This inventor had also observed that "the operation [coking] is, moreover, effected more rapidly, and as the contents of the retort diminish in volume, the coke produced may be withdrawn in a single lump."

These effects have been confirmed by myself, as I was led to mix coke-breeze with coal as a result of an investigation on the influence of faults on coal-seams. Souquière, however, appears to have been concerned only with the manufacture of metallurgical coke at high temperature, and his process is valuable for that purpose, although little use has been made of it, probably for the want of publication. He noted the diminution in volume resulting from the process; but as expansion gave comparatively little trouble in high-temperature work, the importance of this aspect of the question appears to have been overlooked.

Coke-breeze was for many years a worthless product, and it is therefore unfortunate for low-temperature pioneers that advantage was not taken of this remedy for swelling coals at a time when breeze was being wasted as ballast, etc. High-temperature coke or coalite-breeze may be used for this purpose in suitable proportions that must be determined by laboratory tests for any given coal. Not only is the density, toughness, and hardness of the coke, or semi-coke, increased, but its texture may be

made much more uniform by suitable blending. Spongy coke need not be tolerated either in coke-oven work or in low-temperature retorts. I have carried out numerous experiments on many coals from South Wales, Yorkshire, Durham, and Kent, and have invariably been successful in preventing the expansion of coals that normally swell. Practically all the seams from the eastern part of the Welsh Coalfield will respond to treatment in this way, and the more important of the Yorkshire coking coals can also be beneficially mixed with breeze.

Heat-transmission in Coking.—Another difficulty in the manufacture of semi-coke is that of obtaining sufficiently rapid heat-transmission through the charge of coal. Coal is a bad conductor of heat. Probably this difficulty led Parker to propose using retorts with an internal diameter of from 4 to 6 inches (British Patent No. 18,118, 1907). Tozer (British Patent No. 20,158, 1909) introduced internal longitudinal ribs

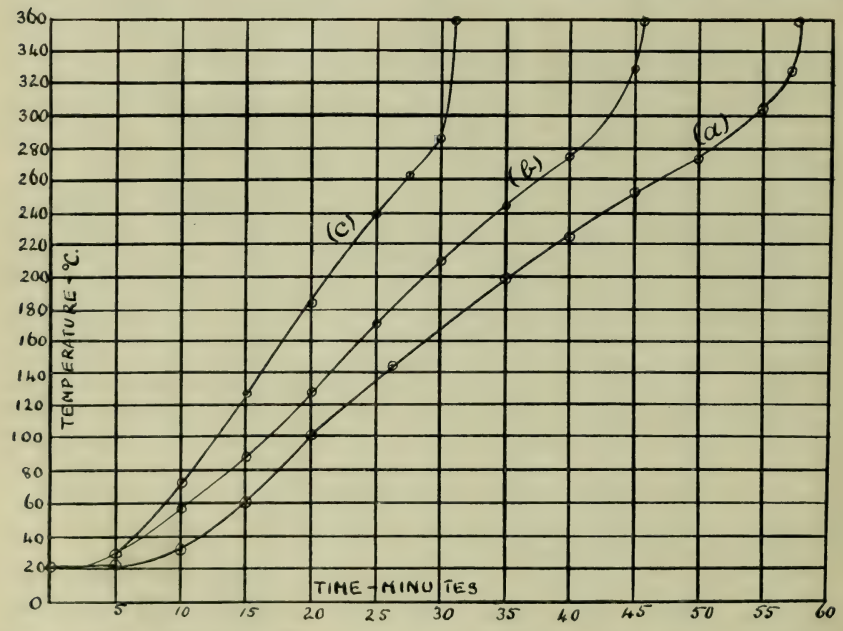


FIG. 2.—HEAT-TRANSMISSION CURVES: (*a*) RAW WELSH COAL; (*b*) SAME WELSH COAL MIXED WITH 20 PER CENT. OF COKE-BREEZE; AND (*c*) SAME WELSH COAL MIXED WITH 30 PER CENT. OF COKE-BREEZE.

into tubular retorts to enable the charge to be more rapidly heated. Cooper (*By-Product Coking*, page 30) has shown that for more than half the carbonizing period the temperature of the interior of the charge does not reach more than about 200° to 300° Cent., and one of his charts shows that after 16 hours the temperature in the middle of a coke-oven charge did not exceed 120° Cent. where the flue temperature was between 1,060° and 1,070° Cent.

Souquière in the specification above quoted had claimed that the coking process was effected more rapidly, although possibly he did not appreciate the true cause of this. Coke consists of carbon and ash. As carbon is a better conductor than coal, it occurred to me that the conductivity of a charge of coal would be increased by the addition of fine coke. Experiments were therefore carried out to demonstrate this, and 200 grammes of coal were heated in a fireclay crucible shielded from

draughts. When the conditions were such that identical heat-transmission curves could be obtained in successive experiments with the same coal, a given coal was taken as a standard and a series of tests carried out. The temperature of the charge was recorded by a thermometer placed at a certain fixed depth in the coal. Successive experiments were made with the coal and with mixtures of coal and coke in varying proportions. The curves shown in Fig. 2 illustrate the increased conductivity resulting from the addition of coke. It will be seen that with coal alone $57\frac{1}{2}$ minutes elapsed before the centre of the charge reached a temperature of 360° Cent., at which temperature the experiment was stopped. With a mixture of the same coal and 20 per cent. of breeze, the time taken was $45\frac{1}{2}$ minutes; while with 30 per cent. of coke, the temperature was reached in 31 minutes.

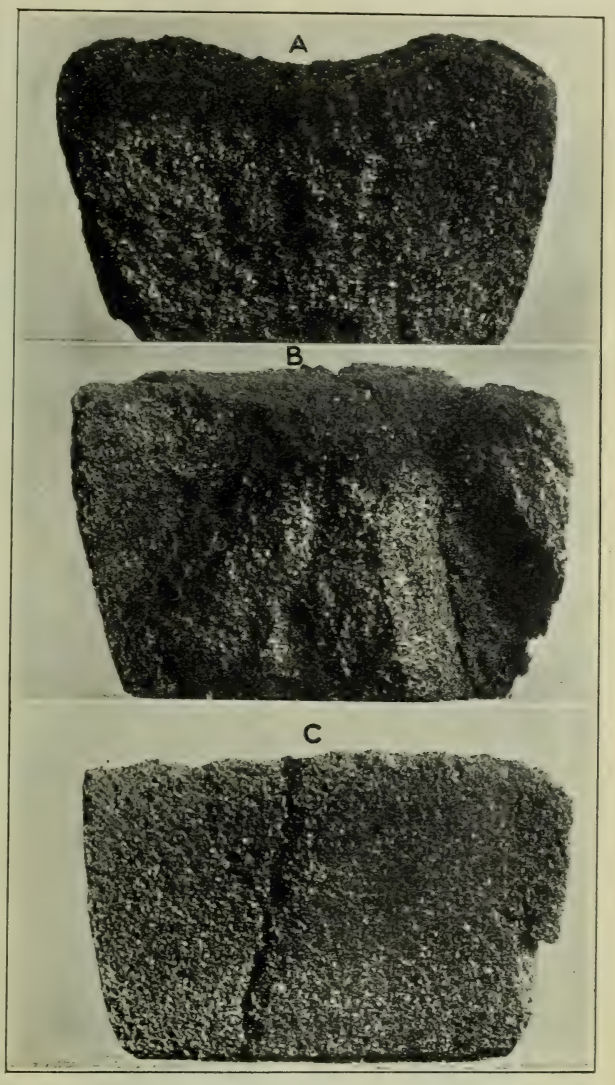


FIG. 3.—PARTLY-CARBONIZED CHARGES OF WELSH COAL: (*A*) UNTREATED; (*B*) MIXED WITH 20 PER CENT. OF COKE-BREEZE; AND (*C*) MIXED WITH 30 PER CENT. OF COKE-BREEZE.

The decomposition zone shown in Fig. 1, on account of its highly-porous structure, has a retarding effect on the transmission of heat. The maximum rate of heat-transfer through the mass, consistent with the formation of suitable coke, is obtained only when the condition of the charge is such that no excess binder is present. The series of photographs shown in Fig. 3 emphasize this point. (*A*) is a specimen of partly-carbonized untreated coal obtained as just described, the heat-transmission curve for which is shown in Fig. 2 (*a*). Here the cellular zone is very pronounced. In Fig. 3 (*B*) the cells are much smaller, and this charge showed greater

conductivity, as will be seen from the graph in Fig. 2 (*b*). The decomposition zone in (*C*) has practically disappeared, and the heat passed through the charge with greater rapidity on this account.

Another way in which the increased rate of carbonization can be demonstrated is by partly carbonizing charges of treated and untreated

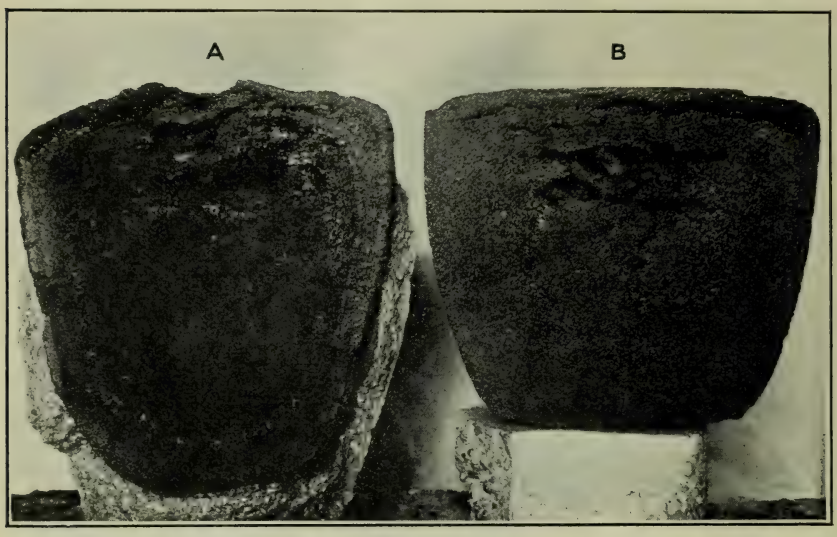


FIG. 4.—PARTLY-CARBONIZED CHARGES: (*A*) THORNCLIFFE COAL; AND (*B*) SAME COAL MIXED WITH 40 PER CENT. OF COKE-BREEZE.

coal side by side in a furnace. Fig 4 (*A*) and (*B*) shows photographs obtained from experiments of this kind. Charge (*A*) consisted of Thorncliffe coal, and charge (*B*) of the same seam with 40 per cent. of breeze added. Both were put into the muffle together at a temperature of 900° Cent., and were withdrawn after 15 minutes (normally, 40 minutes would be required to complete carbonization). It will be seen that (*B*) is carbonized practically to the centre, while the heat had not penetrated to a greater depth than $\frac{3}{8}$" inch in (A); the core of the latter was quite unfused, and fell away as dust.

FIG. 5.—WELSH COAL SPECIALLY TREATED TO REDUCE THE DECOMPOSITION ZONE.

The increased conductivity is, therefore, not due solely to the presence of carbon in the form of fine coke, but also to the destruction of the decomposition zone as a result of utilizing the surplus cementing-material to bind the inert coke. This zone will also disappear if the binder is partly destroyed by other means. Fig. 5 shows a charge of

the same coal as that in Fig. 3 (*A*) which had been subjected to a preliminary treatment, but to which no breeze had been added; while Fig. 6 shows the coke from an untreated Wrexham coal which normally contracts on heating. The corresponding curves are shown in Fig. 7.

FIG. 6.—WREXHAM COAL, IN WHICH NO DECOMPOSITION ZONE IS PRODUCED.

Application of Coke-breeze.—Results similar to those described were obtained with other coals mixed with coke. It will be seen, therefore, that the beneficial effect of this process is two-fold—(1) it prevents the expansion of coal, and (2) increases the conductivity of the charge, thus reducing the time required for carbonizing. The proportion of inert matter to be added must be determined in the laboratory. With every strongly caking coal there will be a certain percentage of breeze which will give the best results. The addition of more than this amount of breeze will tend to reduce the strength of the coke, but a range of 5 per cent, or so with coals of a high coking index

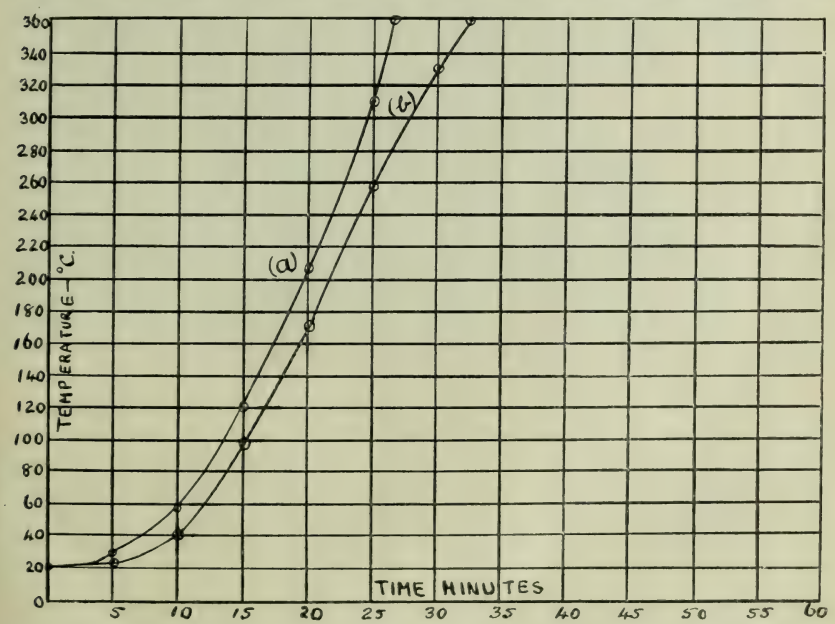


FIG. 7.—HEAT-TRANSMISSION CURVES FOR COALS SHOWN IN FIGS. 5 AND 6.

will not affect appreciably the quality of the product, so that no academic refinement need be insisted on in practice.

It should be pointed out, however, that this process, in order to be successful, must be carried out scientifically and systematically. and breeze of suitable mesh used. In a case which recently came under my notice an attempt was made to use coke which had not been suitably

pulverized, but had simply passed through a gravel-screen. Expert advice was available, but not sought, and the result was disastrous so far as the charges in question were concerned. Properly applied, the process may be carried out usefully both in coke-oven practice and in low-temperature retorts.

An idea of the effect of breeze additions on the crushing-strength of the resulting coke may be gathered from the results contained in the following table. Test-pieces of coke were made in alundum crucibles heated for 7 minutes in an electric furnace at a temperature of 900° Cent. With raw coal no suitable test-pieces could be obtained which would stand a load greater than 100 pounds.

Coal.	Percentage of breeze added.	Dimensions of test-pieces.		Crushing-load.	Remarks.
		Diameter.	Depth.		
		Millimetres.	Millimetres.	Pounds.	
2 ft. 9 in. seam.	20	25 × 22	18	250	Slight crack in specimen.
do.	25	23 × 22	18	265	Do. do.
do.	30	23 × 21	18	395	Compact.
do.	35	23 × 22	18	425	Compact.

III.—A New Low-temperature Product.

Essentials of Good Semi-coke.—The objection often urged against semi-coke is its friability and consequent inability to withstand transport. Good smokeless fuel should be uniform in texture and reasonably hard, so that a minimum of breeze is produced in transport. While 10 per cent. of breeze may not be objected to in consignments to be used for certain purposes, domestic consumers would object to half that amount. In addition to hardness, it should contain sufficient volatile matter to be readily ignitable in the ordinary way: too much volatile matter would tend to produce smoke and waste. The percentage of ash should be low, and the fuel should have a reasonable calorific value. The latter qualities will, of course, depend very largely on the quality of the original coal. Consumers in certain residential districts would also have a preference for a fuel which did not soil the fingers.

The fuel now marketed as semi-coke, while possessing some of the qualities mentioned above, generally lacks hardness and uniformity of texture. There is, therefore, room for improvement in the processes of manufacture in order to overcome these prejudices, which are to some extent justifiable. Moreover, the fuel must be produced in bulk and at a price that will compare favourably with that of coal. By the use of suitable coal, or by a proper pre-treatment of the coal, these results can be obtained.

Hard Semi-coke.—It has already been stated in the discussion of coke-breeze treatment that coke and semi-coke of uniform density and texture can be obtained. Two specimens of semi-coke are shown in (*A*) and (*B*) in Fig. 8, the former being obtained from coal alone and the latter from a sample of the same coal mixed with fine coke. Both charges were heated side by side in a muffle-furnace at a temperature of 750° Cent. The coal used in the experiment is one that usually expands about 100 per cent. at a temperature of 750° Cent., but which contracts if from 50 to 70 per cent. of coke-breeze is added before carbonization. This is an extreme example of an expanding coal. It will be observed

that (*A*) is exceedingly spongy, while (*B*) is quite homogeneous in texture. A product identical with (*B*) can also be obtained by another process which I recently worked out, particulars of which may be published on some future occasion. The yield of breeze from sample (*B*) will be comparatively small, as the charge was withdrawn from the small retort in one lump that could be sawn; about 1·5 per cent. of breeze was produced during carbonization of a 400-gramme charge.

It will be obvious that (*B*) would withstand transport much better than (*A*), and, owing to its texture, would be more likely to give satisfaction to the consumer. From experiments with similar mixtures, the crushing-strength and toughness of treated charges were found to be greater than those of untreated charges. The hardness, however, as distinct from toughness, can be considerably increased even when carbonizing at 750° Cent. One of the hardest cokes I have yet seen was

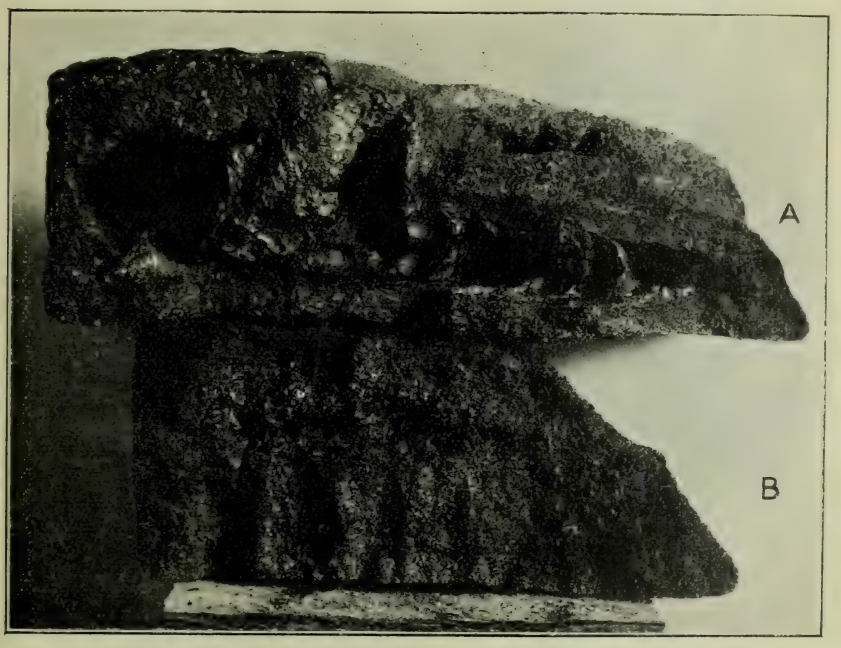


FIG. 8.—KENT COAL: (*A*) UNTREATED; AND (*B*) MIXED WITH 50 PER CENT. OF COKE-BREEZE.

prepared at that temperature, and the sample in question would withstand transport equally as well as anthracite; in fact, a product resembling anthracite may be obtained from certain coals at 750° Cent.; and, at a much higher temperature, a product resembling graphite may be obtained from the same coal.

Causes of Hardness and Lustre in Coke.—The earlier prejudice in favour of beehive as against bye-product coke was due to the superior hardness and lustre of the former. If a section of a charge of beehive coke be examined closely, it will be seen that the lower portion, as shown in Fig. 9, is steel-grey in appearance, hard, and compact. The upper portion has a silvery lustre and a smooth granulated appearance, *but only where the coke was exposed to the hot gases above the charge*—that is, on the upper surface and in the cracks caused by contraction of the coke during the process of its formation. Cracks develop more readily

in the lower section than in the upper part, indicating that the silvery surface-film exerts a cementing effect on the latter. In a similar manner, but on a smaller scale, this effect may be observed in small crucible charges. If a coal that is liable to swell is heated in a furnace, it is sometimes observed that secondary cracks are formed in the mass, through which fused coal finds its way. The surface of this portion has a similar appearance to that of the silvery beehive coke. In both cases this effect has occurred in the upper portion of the charge where the decomposition of some of the hydrocarbons, with consequent deposition of bright carbon, has taken place.

Possibly, also, similar action plays a part in giving the coke its typical steel-grey lustre. At any rate, a bright hard coke can be obtained at a temperature of 750° Cent. by causing some hydrocarbons to be decomposed in passing through the coke.

Fig. 9.—Beehive Coke.

Fig. 10 shows examples of cokes prepared at 750° Cent., in which a deposition of carbon has taken place in the outer shell of coke. In this case the coal was first subjected to an inexpensive preliminary treatment. It will be observed that each specimen of semi-coke is surrounded by a bright and well-defined band that is particularly dense and hard, and which emits a fine metallic ring when struck. Its lustre is almost silvery, and it has the appearance of metallurgical coke rather than of semi-coke. It breaks with a slaggy fracture. The interior of the charge is black in appearance and more porous than the bright zone.

It would appear at first sight that the bright coke would be difficult to ignite, and one would expect the black coke to burn away readily, leaving the bright shell to be consumed later. Such, however, is not the case : the whole of the fuel ignites and burns at a uniform rate.

The shape of the crucible used in these experiments has little influence on the result, a similar result being obtained in D-shaped muffles with 400-gramme charges. Fig. 11 shows portions of such charges. A test-piece from one of these charges, 0·72 square inch in area and $\frac{27}{32}$ inch deep, crushed at 825 pounds.

This semi-coke does not possess the quality of *toughness* to the same degree as when coke-breeze is mixed with the coal, but toughness is not so essential in a domestic fuel as it is in blast-furnace coke. The toughness, however, can be increased, if desired, by the addition of breeze. As a large proportion of the faces of each fragment is protected by very hard coke, the waste in transport will not be considerable, and will be much less than in the case of ordinary coalite. Another advantage is that the fuel is clean to handle, although this is a minor consideration.

Suitability of Coals for Low-temperature Carbonization.—In the ordinary way, swelling coals should be avoided; but if advantage is taken of the above-mentioned processes, any swelling coal may be used successfully. The cokes shown in Fig. 10 were obtained from the following coals:—Parkgate (*a*), Thorncliffe (*b*), No. 2 Rhondda (*c*), Big Rock (*d*), Silkstone (*e*), and Haigh Moor (*f*). Many other coals have also been

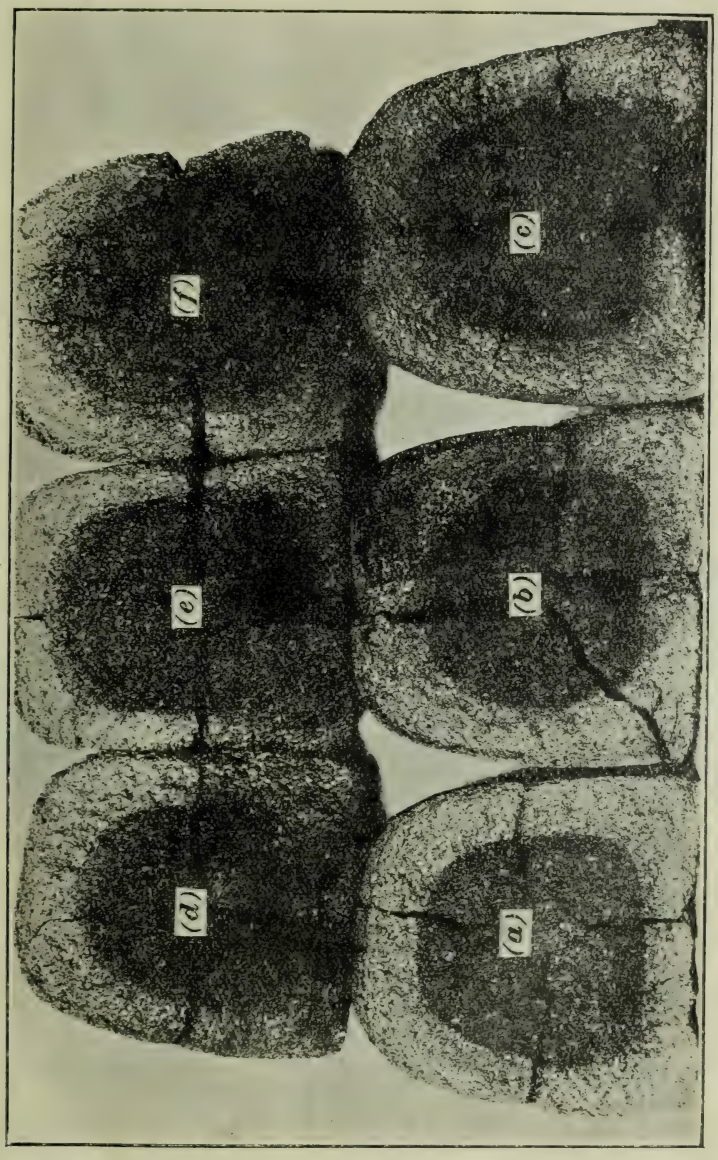


Fig. 10.—Semi-coke with Bright Outer Zones: (*a*) Parkgate; (*b*) Thorncliffe; (*c*) No. 2 Rhondda; (*d*) Big Rock; (*e*) Silkstone; and (*f*) Haigh Moor.

tried, and with similar results; in fact, practically all English and Welsh coals, excepting anthracite, can be used with success. Of course, coals low in volatiles, especially if of good quality, would not be used on account of the low yield of bye-products. Moreover, the resulting semi-coke is really too dense in structure. In Fig. 12 is shown the product obtained from a coal of low volatile matter. It would hardly be correct

to describe this as a coke, as it is devoid of cellular structure. It possesses more of the characteristics of anthracite, both as regards lustre and hardness, and may be said to be sub-anthracitic. The bright outer zone is also seen in this specimen.

In order to test the crushing-strength of this coke, a test-piece having the following dimensions was cut from it and tested in an Adie testing-machine adjusted for making crushing-tests:—Depth of specimen, $1\frac{3}{16}$ inches; maximum area, 0·9 square inch; minimum area, 0·76 square inch. In the test a fragment broke off at 1,450 pounds, and the beam fell at 1,475 pounds, giving a crushing-strength of 1,640 pounds per square inch. Fig. 13 (*A*) shows the test-piece (actual size) after crushing. The specimen shown in Fig. 13 (*B*) was tested for resistance to impact by dropping a 300-gramme weight on it from a height of 3 feet. The piece was cracked, as shown, and produced a very small quantity of breeze.

Production of Semi-coke in Bulk.—It has been shown in the fore-

FIG. 11.—SEMI-COKE WITH BRIGHT OUTER ZONES, MADE IN D-SHAPED MUFFLES.

going remarks that semi-coke of a suitable degree of hardness, density, and toughness can be produced in the laboratory by pre-treating the coal before carbonization, the preliminary treatment also serving to increase the heat-conductivity of the charge while at the same time preventing expansion. The desired result can be obtained whether charges of 1 gramme or 2,000 grammes are used, the form of the retort having little influence on the quality of the product. These experiments lead me to predict that semi-coke can and will be produced in bulk by carbonization in coke-ovens and in gas-retorts, using standard plant. A good product can be obtained in the manner described above, but the best products will be got by the process which yields bright and hard semi-coke, particulars of which may be published on another occasion.

That such a fuel should be placed on the market admits of no discussion. The public have long been convinced of the wasteful way in which coal is being consumed in their own grates, and of the evils of smoke and fog. To some extent, however, they are unable to help themselves, and it remains for coal-producers and carbonizing firms to supply them with

a good smokeless fuel of first-class heating qualities and having all the essential properties previously mentioned. Such a fuel would also

FIG. 12.—PARTICULARLY DENSE SEMI-COKE WITH BRIGHT OUTER ZONE, FROM A WELSH COAL.

satisfy those having a prejudice for the open fire. When the supply becomes ample and continuous, the market will be assured.

FIG. 13.—(*A*) TEST-PIECE AFTER CRUSHING; AND (*B*) SPECIMEN CRACKED BY IMPACT OF ABOUT 9 FOOT-POUNDS.

The experimental work which forms the basis of this paper was carried out in the Fuel Laboratories of the Imperial College of Science and Technology, and I gratefully tender my best thanks to the College authorities for the facilities afforded me.

Dr. G. Weyman (Newcastle-upon-Tyne): I am particularly interested in this paper, although I am concerned chiefly with high-temperature work. The low-temperature phases must first be passed through before the high temperatures are reached, and it is, I think, now realized that a great deal of our trouble to produce high-temperature products is in relation to what happens during the period in which the coal reaches the change which corresponds to low-temperature carbonization, when coal reaches a temperature of from 400° to 500° Cent. Hence work of this sort is just as useful to those who deal with high temperatures as to those who deal with low-temperature work. There are one or two points in connexion with which I do not quite follow Mr. Roberts. He speaks of the binding-material as being a binding-material *per se*, as a sort of cement which cements in the ordinary way. I think, however, the structure of coke is usually regarded as being due to the carbon film that forms when the cement-resin decomposes. The whole of the binding-material must really decompose before it can act as a cement.

I am sorry that Mr. Roberts has made no reference to the work of Mr. Illingworth, published in 1920, and dealing with the theory of coking and the formation and composition of these resinous bodies. Mr. Illingworth's researches resulted in his isolating these resins, and he found that in coking coal 5½ per cent. of resins must be present. The cellular structure of the coke, although partly due to the decomposition of non-binding material, is also partly due to the decomposition of resins. The structure of coke and its porosity is undoubtedly affected by the rate of carbonization. In certain cases it has been noticed that the resins may be so liquid, and subject to such big internal pressure, that the liquid itself is forced to the centre of the charge, up through the centre, and actually comes to the free space where, subject to intense heat, a spongy coke is produced, and this I have seen occur at ovens very often. It is a very porous substance. The expansion during coking is extremely troublesome in gas-works, particularly in vertical-retort plants, where expansion of that sort can "hang up" the charge for a considerable time. Whilst it is true that certain coals do not appear to expand when heated, I am of opinion that there really is expansion (that is, increased porosity), because the specific gravity of the coke is never equal to that of the coal. The expansion, I take it, is not apparent, owing to the presence of the free space always found in coal-charges. The free space in ordinary mixtures of unscreened coal may be over 40 per cent., and that space will be taken up for expansion. Mixtures of coke-breeze with coal, before introduction into the retort, have been tried on many occasions in the gas industry—chiefly for the purpose of getting rid of the coke-breeze. The experiment has never been entirely successful, because the resulting coke was always found to be decidedly softer than when raw coal was used. There is certainly a more rapid penetration of heat into the centre of the charge where coke-breeze is admixed; but the point that occurs to me is whether the rate of carbonization, owing to that extra pressure on it, would be such as to allow the amount of breeze—say, 30 per cent.—to be put through 30 per cent. quicker; otherwise there would be a loss on the throughput of coal to be carbonized. One of the points low-temperature advocates are up against is, I take it, getting the coal through the retorts at a rapid rate. In reference to the increase in radiant efficiency when the coal is burnt, Dr. Fishenden finds that this is due to its porosity. From the details given of the mixtures with which Mr. Roberts experimented it is shown that the cokes were particu-

larly dense, and I wonder whether that extra efficiency would be lost, because, presumably, the porosity to a large extent would be lost.

Mr. W. Diamond (Marley Hill): I quite appreciate that "coalite" is another term for semi-coke. Very great care is required in working a coalite plant. The coal must be in thin layers, whereas in ordinary coke-ovens the layers are about 19 inches. The heat must be passed slowly through the coal in order that this semi-coke may be formed. One great factor that is an advantage is that a greater production of paraffins and carbolic acids results. In low-temperature carbonization the greater part of these products are recovered, but in ordinary coke-oven practice they are destroyed to a greater extent. I remember that 25 years ago higher heats were reached in the gas-works. Prior to that, in the tar of the low-temperature distillation there were greater quantities of benzenes with paraffins and light oils. The anthracene also contained greater proportions of paraffins. Almost immediately after the change was made, it was noticed that the tar from the higher-temperature carbonization in the gas-works was very dense, and contained little benzenes, and the anthracene was practically free from paraffins. Whilst there would be a greater charge on production, there would be a greater return made by the bigger volumes of bye-products recovered. The ammonia would not be so high, as it requires greater heats.

There is a remark in the paper about the glossy brightness of the coke, which is due entirely to the cracking-up of the bituminuous products involved. With regard to the ordinary bye-product oven, this brightness is not attributable to that cause, but to the oxidization which immediately follows ejection from the oven. I take it that Mr. Roberts refers to the brightness on the surface of bee-hive coke. When he states that by mixing the breeze with the coal he obtains a quicker time of carbonization, he is not quite correct. I suggest that, because as Dr. Weyman remarked, he would not get the same throughput of the coal. Certainly, if inert material be put into the coal the time required for carbonization is reduced, because there is not so much free gas or volatile matter to evolve. The time for getting rid of volatile matter is during distillation; when that is accomplished, carbonization is completed, but the addition of coke-breeze does not reduce that time. The effect upon the carbonization depends upon the size and dryness of the coal and the size of the apparatus. Coals carbonized in small gas-retorts naturally come out in a few hours as compared with large ovens of present-day size.

Mr. E. A. Knott (Blaydon-on-Tyne): It seems to me very doubtful whether it will ever pay to carbonize best coking coal at low temperatures, for it means that the resultant coalite has to be sold at the same price, or less, than household coal. I do not think that the public would be inclined to pay more, or even as much, unless they were thoroughly accustomed to cokite. The way to make people use it would be to prohibit the use of raw coal in the hearths. That is an extreme method, but it would attain a very desirable object. I am very disappointed that the paper does not give us the yield of products from the ordinary coke-oven in comparison with the low-temperature oven, as such information would be very useful. I am of opinion that less gas would be got from the low-temperature carbonization, because there would be about 10 per cent. of the volatile matter left in the coke, although the gas would be of higher calorific value. The calorific

values obtained from gases from low temperatures and ordinary practice would be interesting. The yield of sulphate of ammonia, which is a very valuable bye-product, in ordinary practice would be less with low-temperature carbonization. Instead of obtaining the ordinary benzols now produced, they would be more of the nature of petrol and paraffin bodies, which would, however, be suitable for motor purposes. The yield of tar and light oils would probably be greater. The real future in low-temperature carbonization, in my opinion, is not in dealing with good coking coal, but in dealing with what is called "waste" coal. The most valuable field of research will be in finding out how to use that coal. I think the recent coal stoppage has been a great advertisement for smokeless fuel. One could see the great improvement in the atmospheric conditions, and everyone practically used coke for domestic purposes and with complete success.

Mr. E. Seymour Wood (Sunderland): I have been very interested in the paper and discussion, for my first experience of low-temperature carbonization was in India many years ago, when we made an inferior coke called "Poira Coila." Small coal was taken and put between four walls, about 1 to 1½ feet high, burnt between these walls, quenched, and allowed to cool down. In some cases the small coal was burnt in heaps only. The result was a bastard coke, which was an excellent fuel for domestic purposes, and gave off great heat. It was used in the native bazaars and native houses as a smokeless fuel for cooking and heating purposes. In making "Poira Coila" it was found that if the small coal were mixed with particles of previously-made "Poira Coila" a better class of fuel was produced than was the case if made with small coal alone. I believe there is quite a trade going on to-day in this class of smokeless coal for Indian domestic purposes.

Mr. S. Roy Illingworth (Treforest): I am pleased to note that the author emphasizes the fact that the solution of the problem of low-temperature carbonization is, first and foremost, one for the chemist and physicist. Mr. Roberts' extension to British coals of the work of Parr, published in 1910, cannot fail to be of value towards the formulation of scientific basis for carbonization. The view put forward by Prof. Parr,* and endorsed by Mr. Roberts, that the swelling of a coal is due to the presence of a surplus amount of binder, is not in conformity with my own observations on a wide range of coals. I have extended my researches on coals and their carbonization, several papers on which have appeared in the *Proceedings* of the South Wales Institute of Engineers and in the *Journal* of the Society of Chemical Industry. This work demonstrates the fact that the porosity of a coke is conditioned by the thermal stability of the complexes which constitute the binder (γ compound) and the ease with which other substances are decomposed. The amount of the binder is of secondary consideration; the endeavour to correlate the question of porosity with the γ compound content gives rise to many contrary results. Coals therefrom, which contain the same percentage of γ compound, and of which the ash is for all practical purposes the same in amount, behave very differently: one coal may give a dense coke, the other a porous coke. Thermal stability range is the deciding factor. In certain cases that coal which contains

* "The Coking of Coal at Low Temperatures (with a Preliminary Study of the Bye-products,"), by S. W. Parr and H. L. Olin.

the greater amount of binder (γ compound) yields the denser coke. The γ compound in every case was estimated by phenol extraction of the coal, or by the prior depolymorization of the coal-substance.

I am afraid that small-scale laboratory tests on a number of different mixtures of high-volatile bituminous coals with coke or coalite-breeze would prove an uncertain guide to blends suitable for the large-scale operations. The temperature-gradient is an all-important consideration in the carbonization of a charge. My own experience in blending and carbonizing small and large masses is that no definite correlation exists between the results. In a crucible test one obtains a fine hard product; in bulk the same blend gives either a weak or a strong coke: cavities of varying size are found in the centre. Nevertheless, the blending of coals can be achieved from a consideration of the constituents of the individual coals which go to form the blend.

I cannot see that a process based on the blending of coke-breeze and highly-bituminous coals is an economic proposition, especially when upwards of 50 per cent. of breeze has to be added: for, apart from the added expense of mixing, the capacity of the plant is but 50 per cent. of its charge, since in carbonizing only half the charge is virgin coal. The margin of profit for low-temperature work on large coal is very problematical; the plant cannot afford "dead-heads" even in the gallery.

The heat-transmission curves of Mr. Roberts are very valuable, and I trust he will continue his researches on this important matter. There is one point in connexion with rapid heat-transmission of which Mr. Roberts is no doubt aware, but which he has not mentioned. American coke-oven practice recently tended towards the development of very high flue-temperatures in the hope that the time of carbonization would be shortened; whilst such was the case, unfortunately the coke was of a porous nature. The long period of time occupied for the interior of a charge to reach a temperature about 200° Cent. is due mainly to the evaporation of the moisture in the charge; and the beneficial effect on the coke observed in certain cases with wet charges as against dry charges is, in my opinion, due solely to the temperature-lag in the early stages of heating the charge.

We can only hope for a fuller knowledge of the "mechanism" of carbonization by a resolute attack on the chemical constitution of coal; the days of empiricism have passed, and each investigation is a march forward.

Sir George Beilby (London): I have read this paper with great interest, and congratulate Mr. Roberts on this admirable piece of experimental work, which seems likely to have an important bearing on the whole question of coke-oven practice.

It is interesting to note that, although M. Joseph Souquière, in Paris, patented in 1859 a method of blending inert carbonaceous matter, such as coke-breeze, with the coal, since that time very little appears to have been done to make use of this valuable means for the prevention of the foaming of coal during carbonization. The Fuel Research Board have, however, for several years past adopted this method at their works at East Greenwich, on a scale entirely comparable with an industrial-sized plant. This plant consists of a bench of horizontal steel retorts, in which the coal can be introduced in trays, these trays being divided by longitudinal and cross divisions in order to facilitate the conduction of heat into the mass, and also to deliver the final product in cakes of regular size and form.

It was soon recognized that this method did not lend itself to highly-fusible coals, and therefore the bulk of the tests—some 120 in number—have been made with mixtures of the more fusible coals with less fusible varieties, in order that there might be a final slight contraction, rendering the coke-cake easily removable from the mould. This method was shown to parties of engineers visiting H.M. Fuel Research Station during the last week in June, 1921.

With regard to the so-called "expansion" of coals on coking, it should be noted that this is in no sense an expansion of the coal-substance itself, but is due to the foaming and sponging caused by the evolution of hydrocarbon gases while the coal is in the fused state. This foaming is naturally very much reduced by the presence of infusible material, which ensures that the gases escape freely from the semi-solid mass without the production of large bubbles.

A method for the low-temperature assay of coals was described in Technical Paper No. 1 issued by the Fuel Research Board, entitled "The Assay of Coal for Carbonization Purposes; a New Laboratory Method." One of the great advantages of this method is that the behaviour of the coal as regards fusion and foaming can be readily observed in carrying out the operation, and the coals most suitable from this point of view for carbonization can at once be selected. In the case of the more fusible coals, the proportion of the less fusible material which has to be added to produce the desired result can be readily determined in a few hours.

Mr. D. R. Wattleworth (Moresby): Mr. Roberts is to be congratulated on his paper and the important results which he has attained. There are some who would have us believe that low-temperature carbonization has been tried out, and that it is an economic failure; indeed, so much adverse criticism has been levelled against the process that Mr. Roberts and his co-workers are, in my opinion, possessed of great optimism in pursuing their researches. That there is still much to unearth that will prove of value in future developments is instanced by the results published in this paper.

Mr. Roberts's reference to Soquière's work on the mixing of coal and coke is particularly interesting, and it is most surprising that we have not ere this had the matter brought before us more prominently. Coke-breeze has always to be sold at a price far from commensurate with its carbon content, and if it can be utilized in the way suggested, it should prove a very profitable proposition. Unfortunately, only a small proportion of an average breeze would be of the necessary fineness, and crushing or grinding would, of course, add to the cost of production. Again, coke-breeze contains, almost invariably, more ash than the original coke, and, unfortunately, the finer the breeze the greater is the ash-content, so that the quality of the resulting fuel would be slightly impaired by additions. The addition of so much inert matter would also mean the handling of a much greater weight of raw material than at present for a given amount of bye-products recovered. It would be interesting to know what effect, if any, the addition of the coke-breeze would have on the yield of bye-products.

Mr. H. Rook (Cockermouth): Mr. Roberts's paper contains much useful information, and although entitled "Low-temperature Carbonization" many points are noticeable that should interest manufacturers of high temperature coke. The type of coal to be used and the results expected on carbonization leave much to speculation, but experiments carried out along the lines which the author indicates should not allow

any doubt to exist regarding the suitability of the fuel produced for a given requirement. The carbonization zones are particularly noticeable in high-temperature coke when a batch is drawn rather early. The number of zones present varies with the method of working, the fusion and decomposition zones becoming extinct as the " hardening " time is lengthened.

It would be interesting to know Mr. Roberts's limits to the volatile matter left in the coke. If, as stated, the presence of volatile matter is necessary for the coke to be used in existing grates, I do not quite approve of the line of thought. The domestic grate has long been proved a national wasting device, and, instead of the fuel being adapted to the grate, let the grate be designed for the fuel—the most economical fuel to producer and consumer alike. If there is anything distillable in that remaining volatile matter, do not waste it. Otherwise, the semi-coke prepared from suitably-treated coal is as yet the best alternative to coal for domestic purposes. As far as I can see, the use of semi-coke will not necessitate any drastic and immediate re-design of the grate.

Capt. T. W. Adam (Barnsley): Mr. Roberts is to be congratulated on the great value of his research-work, and also on the apparent degree of success that he has obtained in the laboratory.

I should like to know what the actual yields of semi-coke, gas, and residuals were in the laboratory with the various coals, mixtures of coals, and coke-breeze; what Mr. Roberts estimates might be reasonable productions on a large scale; and whether he can give any figures in British thermal units of the value of the gas.

The production of large quantities of gas of a high B.Th.U. (470 to 510 for lighting, or from 200 to 300 for gas-engines) and a high yield of bye-products is essential, as the cost of the semi-coke alone will be considerably above that of coal. Although, as Mr. Roberts states, everybody realizes the great value of the smoke that is wasted annually through the numerous chimneys all over the country, a very long period will be required to educate the public to realize that semi-coke at a higher price than coal makes a better fire, or that it is more economical.

Mr. Roberts's research-work in connexion with the solution of the problem of preventing the expansion of coals which normally swell is undoubtedly of the greatest importance, not only as regards the production of semi-cokes, but also of furnace-cokes. In the latter the reduction of expansion to its lowest limits is essential, especially in the very fast ovens constructed on the latest American principles, when every oven has to be discharged at a fixed time, regardless of the fact whether or not sufficient contraction of the coke has taken place to allow of its being got out of the oven without sticking.

Will Mr. Roberts state how he proposes to carry out cheaply the mixing of slack and coke-breeze? Personally, I think he has, in this respect, set himself a very difficult task. The slack should contain from 8 to 10 per cent. of moisture in order to make a good cake, and the breeze must be perfectly mixed throughout the cake. It would also be of interest if Mr. Roberts would state the ash-contents of the semi-cokes he has produced, both from coal alone and from the coal and coke-breeze mixtures.

Mr. L. Silver (Gravesend): It follows, from Mr. Roberts's explanation of the process of carbonization, that coke is in some ways analogous to a cement-concrete, in which the decomposition product of the " binder " forms the cement that connects the particles of the infusible

constituents of the coal. A coal with " surplus binder " is one in which this cement is more than sufficient to fill the interstices between the particles. If this axiom be granted, it appears obvious that the " coking index " of a coal is no criterion of the hardness or density of the carbonization product, although it does give a measure of the amount of " excess binder " in the coal. This view as to the constitution of coke also affords a possible means of accounting for the formation, from a mixture of coal and coke-breeze, of a product which is stronger than that from the coal alone or the coke from which the breeze was obtained: for with the optimum mixture of coal and coke the " binder " would be just sufficient to fill the interstices between the inert particles, when these are in contact. In this case crushing would be resisted, not only by the strength of the cementing medium, but also by the friction between the particles themselves; and, since the coke from which the breeze is formed gives way on crushing at the weakest planes in the mass, the average strength of the unbroken particles must be higher than that of the original mass. If these conclusions are correct, the strength of the product should increase to a maximum, and then fall off fairly rapidly with increasing proportions of breeze.

The great improvement in heat-transmission effected by the processes outlined in the paper should go a long way towards the solution of the difficulty of getting the valuable liquid hydrocarbon products away from the retort without loss by heat-decomposition. As Mr. Roberts shows, when pure coal is carbonized in a retort or oven the outer layers are at coking temperature, while the interior of the charge is still evolving its low-temperature products, which, in consequence, are partly broken up in passing through the much hotter outer layers. If, however, the heat-transmission is improved by the admixture of coke, or by other treatment, so that the temperature is more uniform throughout the mass, the whole of the low-temperature products will be evolved before any part of the charge has reached a very high temperature, and these products, therefore, have a much greater chance of getting away undecomposed. The speeding-up of the process resulting from improved heat-transmission means, also, that the volatile products pass more quickly from the the retort, so that the chance of decomposition is still further diminished. A higher yield, therefore, of the valuable liquid fuels may be expected, and on this score the success of any low-temperature process largely depends. Similar results should also follow from the application of these methods to high-temperature coke-oven practice. This, in conjunction with the uniformly excellent products obtained by Mr. Roberts from all types of coal, should go far towards ensuring a brighter outlook for the future of low-temperature carbonization.

Mr. John Roberts (London), in reply, wrote: Several speakers have appreciated the bearing of the paper on high-temperature carbonization. In the manufacture of metallurgical coke the chief aim is the production of as large a proportion as possible of hard coke suitable for use in blast-furnaces. The most modern American practice favours the use of pieces retained on a 4-inch screen, and the rejection for furnace use of the smaller pieces which pass through the screen. In this country coke which passes through a 1-inch screen is often rejected, and until recently an inadequate market existed for the surplus breeze. If the breeze were pulverized and subsequently fed on to a belt conveying the coal to the disintegrator, the mixing of coke and coal could be carried out in the disintegrator.

Mr. Wattleworth suggests that the breeze contains more ash than the large coke, but in using one's own make of breeze the percentage of ash in the final coke product will certainly depend on that in the original coal. The yield of bye-products will depend on the amount of *raw* coal carbonized, but the yield of *blast-furnace* coke will depend on whether the breeze is utilized as suggested in the paper. If it became the regular practice in coke-ovens to mix breeze with coal, coke-oven managers would then be concerned only with their own production, which, in many cases, would not be sufficient to reduce expansion of the coal, but would be sufficient to warrant its being used on the score of economy. As Dr. Weyman points out, the throughput of coal to be carbonized may be reduced, but the yield of *blast-furnace coke* per ton of coal would be increased.

With reference to Dr. Weyman's remarks on the binding-material, it should be noted that the fusion of the coal is the first step in carbonization, and the particles become cemented at that stage. The final structure and appearance of the coke will depend on the coking temperature, the blends of coal used, and whether the conditions are favourable for the decomposition of hydrocarbons in passing through the carbonized layers. In view of the fact that in the new low-temperature product described the widest zone of bright coke is produced with the minimum proportion of " binder," consistent with the formation of coke of the required firmness, it appears that the structure of the coke is due, not only to the decomposition of the " cement-resin," but to other products also. The lustre does not appear to be due to oxidation, as suggested by Mr. Diamond. This new product is certainly denser in the outer layers than ordinary coalite, but, strangely enough, the bright and black portions of a given charge burn with equal rapidity. Whether the extra rate of heat-efficiency would be lost on account of the increased density would have to be determined under the conditions adopted by Dr. Fishenden.

The paper was devoted mainly to the question of carbonizing, and to avoid confusing the issue the yields of bye-products were not discussed. Moreover, that aspect of the question has been previously dealt with by other workers, and we hope soon to be favoured with the results of the extended series of trials carried out under Sir George Beilby's direction at Greenwich. These promise to be of the greatest importance, as the trials have been run on a scale comparable with industrial practice, and are calculated to give much greater satisfaction than any figures which I may give. However, in reply to Mr. Rook and Capt. Adam, it may be stated that semi-cokes contain from 6 to 12 per cent. of volatile matter, the amount depending on the coal used and the coking temperature. At 750° Cent. about three-fourths of the volatile matter of the coal is driven off, as high-volatile coals liberate their gases more readily than low-volatile coals. The yield of semi-coke is, therefore, greater and the yield of gas proportionately less than in coke-oven practice. The colorific value of the gas ranges as a rule between 600 and 650 B.Th.U.

Mr. Rook is opposed to allowing any volatile matter to remain in the solid fuel. One essential of a semi-coke is that it should contain sufficient volatile matter to render it easily ignitable in an ordinary fire-grate. Gas manufacturers and coke-oven operators aim at obtaining the maximum yield of gas from the coal, offering to the public for domestic consumption the residual coke and fuel in the handy form of gas. If these fuels satisfied the public, low-temperature carbonization would have been killed at its birth; but the fact remains that the domestic consumer

does not like high-temperature coke, on account of the difficulty of its ignition in ordinary grates; they still prefer raw coal, and use it in a wasteful manner. There is, therefore, an urgent need of a fuel such as semi-coke. When the problem of producing this in bulk—say, in coke-ovens—has been solved, the drastic step of prohibiting the use of raw coal in the hearth, as proposed by Mr. Knott, may then be put into effect.

Mr. Illingworth in his valuable researches puts forward the view that the primary factor in determining the swelling of coal and the porosity of a coke is the thermal stability of the binder (γ compound), and that the amount of the binder is of secondary importance. Without desiring at this stage to contest this view, I may state that in my experience, with one exception, the expansion of coals has been found to be proportional to the coking index. Curiously enough, the coal having the highest coking index—a cannel coal from South Glamorgan—contracted on coking. The volatile content of this coal was 53 per cent. When carbonized in the raw state, it yielded a worthless coke that was extremely spongy; but it was capable of binding 80 per cent. of coke-breeze—four times its weight—and the mixture yielded a very desirable coke.

The temperature-gradient will have an important bearing on the carbonization of a charge, but so long as this fact is borne in mind laboratory tests are of value. For instance, it might be found in the laboratory that 20 per cent. of inert matter gave the best results with a certain coal. On account of the temperature-gradient and the length of time part of the charge would have to remain below 300° Cent., it would probably be found that 20 per cent. of inert matter would reduce the coking index below workable limits, and that 15 per cent. would give the best results in a retort.

From what has been said it will be seen that Mr. Silver's view that the coking index of a coal is no criterion of the hardness or density of the coke is correct, as is also his conclusion that in using certain coals the strength of the product increases to a maximum and then falls off rapidly, with increasing proportions of breeze. This was actually found to be the case in the crushing tests on samples of coke. Large-scale trials only would determine whether a higher yield of products would result from the speeding-up of the process as he predicts.

It is interesting to note that, according to Mr. E. S. Wood, a mixture of "Poira Coila" (in other words, semi-coke) and coal gave better results than coal alone in the manufacture of smokeless fuels in India.

A considerable part of the paper and a great deal of the discussion centred round the blending of breeze and coal, but it should be noted that in the product described in the third section of the paper no breeze is used. Expansion, however, is prevented, and the semi-coke possesses qualities which make it superior to that produced by other means. A description of the process is being deferred, however, until large or semi-large scale tests have been carried out.

I thank all those gentlemen who have contributed to the discussion for the very cordial reception given to my paper.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM OCTOBER 2ND TO OCTOBER 29TH, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	Oct. 2	0	17′·5	16′·5	16′·0	15′·0	16′·0	18′·5	20′·5	20′·5	18′·5	17′·0	14′·5	15′·5	17′·0
Mon. ..	3	0	16·5	16·0	16·5	15·5	14·0	18·0	22·0	21·0	18·0	16·5	16·0	15·5	17·0
Tues. ..	4	0	15·0	15·0	15·0	15·0	15·0	18·0	22·0	21·0	17·5	16·5	13·5	14·5	16·5
Wed. ..	5	2	16·5	16·5	16·5	14·5	13·5	17·5	21·5	20·5	17·5*	11·0*	11·5*	15·0	16·0
Thur. ..	6	1	13·5	12·0	15·0	14·5	14·5	20·0	22·0	20·0	17·5	16·5	13·5	15·0	16·0
Fri. ..	7	2	17·0	15·5	15·5	14·5	15·0	19·0	20·5	18·5	17·0	13·5*	10·5*	10·5*	15·5
Sat. ..	8	2	10·5*	16·0*	22·5*	25·0	24·5	24·5	24·0	21·5	18·5	13·5	13·5	16·5	19·0
Sun. ..	9	1	13·5	16·5	13·5	13·5	14·0	18·0	20·5	20·0	17·5	16·5	14·5	16·0	16·0
Mon. ..	10	0	15·5	16·0	15·5	15·0	14·0	16·5	20·0	19·0	16·0	16·0	16·0	15·5	16·5
Tues. ..	11	2	15·5	15·5	16·5	17·0	16·0	18·0	21·5	20·5	15·5	11·5	8·5	5·5*	15·0
Wed. ..	12	2	4·5*	12·5*	15·5	15·5	14·5	17·5	20·0	19·0	15·5	14·5	12·0	15·5	14·5
Thur. ..	13	0	16·0	16·5	15·5	14·5	13·5	17·0	20·0	19·5	16·5	15·5	15·5	15·5	16·5
Fri. ..	14	1	16·0	15·5	15·5	14·0	14·0	17·0	20·5	20·5	19·0	15·5	14·5	13·0	16·0
Sat. ..	15	1	14·0	16·5	15·0	13·5	14·0	18·5	22·5	20·5	16·0	15·5	15·5	15·5	16·5
Sun. ..	16	0	16·0	16·0	16·0	15·0	14·5	18·5	21·5	20·0	17·5	16·5	15·0	15·5	17·0
Mon. ..	17	0	16·0	16·0	16·0	14·5	13·5	17·5	20·5	18·5	17·0	16·0	14·0	15·5	16·5
Tues. ..	18	0	16·0	15·5	15·5	14·5	14·0	19·5	22·5	20·0	18·0	17·0	16·0	15·0	17·0
Wed. ..	19	0	14·5	14·0	14·5	14·5	14·0	18·0	20·0	18·0	16·5	15·5	15·0	15·0	16·0
Thur. ..	20	0	15·0	15·5	15·5	14·5	14·0	17·5	19·5	19·0	17·5	15·0	14·0	15·5	16·0
Fri. ..	21	1	15·5	15·5	15·5	17·0	15·5	20·0	23·5	19·5	18·0	15·5	11·5	13·5	16·5
Sat. ..	22	1	15·5	16·0	15·5	14·5	14·0	17·5	20·5	19·5	18·0	14·0	14·5	14·0	16·0
Sun. ..	23	1	15·5	16·0	16·5	15·5	15·0	18·0	20·5	19·5	16·5	15·5	14·0	15·0	16·5
Mon. ..	24	0	16·0	16·0	16·0	15·0	13·5	18·0	21·0	20·0	17·0	15·0	14·5	15·5	16·5
Tues. ..	25	0	16·0	15·5	15·5	15·5	14·0	17·5	19·5	18·0	15·5	16·0	15·0	14·5	16·0
Wed. ..	26	0	14·5	15·5	15·5	15·0	13·0	16·5	21·0	19·0	18·5	17·0	14·0	14·0	16·0
Thur. ..	27	1	15·0	17·0	15·5	14·5	15·0	19·0	23·0	20·5	18·0	16·5	14·5	12·0	17·0
Fri. ..	28	1	13·5	15·0	15·5	14·0	15·5	19·0	20·5	18·0	17·0	15·5	11·0	9·5	15·5
Sat. ..	29	1	13·0	14·5	16·0	15·0	14·5	19·5	21·5	19·0	17·5	13·5	13·5	15·5	16·0

Diurnal Inequality (*i.e., departure from mean value for day*).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
October, 1920	−1′·6	−1′·2	−1′·4	−0′·9	−1′·0	−1′·0	−1′·5	−2′·2	−2′·0	−0′·2	+2′·6	+4′·9
September, 1921	−1·1	−1·3	−1·7	−1·6	−1·9	−2·5	−3·5	−3·5	−2·4	−0·1	+2·6	+4·8
September, 1920	−2·3	−1·7	−1·9	−2·4	−1·9	−2·0	−2·4	−2·6	−1·8	+0·5	+3·3	+5·5

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
October, 1920	+5′·7	+5′·3	+3′·8	+2′·0	+0′·9	+0′·4	−0′·6	−1′·4	−2′·3	−3′·1	−3′·0	−2′·1
September, 1921	+5·8	+5·2	+3·6	+2·1	+1·0	+0·2	0·0	−0·6	−1·1	−1·2	−1·4	−1·4
September, 1920	+6·4	+5·5	+4·1	+2·0	+0·9	+0·5	−0·6	−0·7	−1·2	−2·1	−3·0	−2·1

* Large disturbances during this interval.

Mean Value for Month.

October, 1920.	September, 1921.	September, 1920.
14° 28′·1.	14° 17′·6.	14° 28′·7.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The normal value for an hour is the mean declination for that hour in the month, derived from quiet days only, or from all days excluding those of character "2." On a day of character "0" declination at any hour will usually be within about 3′ of the normal. On a day of character "1" the departure from the normal will usually not exceed 5′, but it may occasionally be as much as 10′, or even more. On a day of character "2" the departure from the normal will seldom exceed 20′, but departures of 30′, or even on extreme occasions of 1° or more, may occur.

The above values were obtained from measurements made after "smoothing" the curves.

THE MINING INSTITUTE OF SCOTLAND.

GENERAL MEETING,

HELD AT THE ROYAL TECHNICAL COLLEGE, GLASGOW, AUGUST 13TH, 1921.

MR. SAM MAVOR, VICE-PRESIDENT, IN THE CHAIR.

FORMATION OF A STUDENTS' SECTION.

Mr. JOSEPH PARKER (Cowdenbeath) moved and Mr. WILLIAM WILLIAMSON (Hamilton) seconded a resolution that the recommendation of the Council for the formation of a Students' section in connexion with the Institute should be adopted.

The motion was agreed to unanimously.

The discussion on Mr. H. M. Cadell's paper on "Coal-mining in Spitsbergen" was closed.

DISCUSSION OF PROF. HENRY BRIGGS'S PAPER ON "PHYSICAL WORK AND THE HUMAN MACHINE."*

Mr. JAMES COOPER (Edinburgh) wrote: The question naturally arises, can the results set forth in the paper be made of use by taking better care of the energy of the workers so as to increase the productivity of of our mines? The problem of providing means whereby the miner can reach his working-place in the best physical condition seems to be easy of solution, and, in fact, in many mines the men are already being transported to the coal-faces by haulage. The transport of workers has a double advantage, as the men sitting at rest not only conserve their energy, but time is gained in travelling the distance.

Although there is such transport of men along the main roads, that on rise inclines is non-existent. In many collieries long inclined roadways have to be traversed, and, as shown in the paper, it is on such inclines that energy is expended at a greatly increased rate. Roads parallel to the coal-inclines might therefore be arranged, and efficiency would be increased thereby in increased physical fitness of the men.

One point not dealt with in the paper, characteristic of the everyday work of mines, is that of men doing work in a constrained position. In many cases workers have to walk long distances in a stooping manner in low roadways. Ergometer tests where the subjects would be doing the work in cramped positions would perhaps show some further illuminating results.

During recent years American engineers have studied the motions of men while at work, with a view to eliminating needless actions and so increasing efficiency. Some authorities claim that this has led to greater productivity, and the large *per-capita* output in the United States of

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 26.

America lends some credence to their claim. In the paper under discussion a new aspect of the human factor has been put forward, and the data obtained should be carefully studied in connexion with its economic bearing on the life of the mining industry.

Dr. Briggs has introduced a unique subject to the Institute, namely, the metering of the human factor in mining. For a number of years many kinds of mechanical devices have been applied to measure consumption of energy used by power-machines at collieries, and it seems an opportune time now to consider the human machine—the most expensive form of energy used in the industry.

As one who was closely associated with the work described in the paper, the method of estimating the fitness of a man was in my own case correct. At two different periods I acted as a subject of experiment, and the results on both occasions were a true measure of my physical condition, the percentage fitness in the two cases recording a period of indifferent health and normal condition respectively in correspondence exactly with my personal knowledge.

In the trainings of brigades at the mine-rescue station the men were asked to carry out many of the walking experiments, and although no exact breathing measurements were recorded, all the teams were unanimous in confirming the differences of effort required in working at varying rates.

Several of these tests are interesting from the "rate-of-walking" point of view. All the men considered that a speed of 3 miles per hour was the most suitable on the surface, while on an underground level $2\frac{1}{2}$ miles per hour required the same effort. A rate of 2 miles per hour on the level underground forced the men to hang on their step; while on inclines of about 1 in 8 to 1 in 10, 2 miles per hour was sufficient.

The series of experiments carried out at the Newbattle and Lingerwood Collieries and at Burdiehouse Mine are valuable in recording the effort required in traversing inclines, these showing the greatly increased energy expended.

The Chairman (Mr. Sam Mavor): This is a paper of very great practical interest to the mining industry. It is not a mere fad. The importance of formulating the conditions under which human effort can be most efficiently expended is a matter that peculiarly affects mining, in which so large a proportion of the underground work is done by muscular energy.

Mr. Joseph Parker (Cowdenbeath): The paper is a very important one, in that it affords the means of measuring the effects of different classes of work on men. There is no question that nowadays the problem of fatigue is coming very much to the front, and it is well known that if work is to be performed to the best advantage, fatigue must be avoided at all costs. Mr. Cooper has referred to the experiments that have been made in the United States, and many of us are fairly well acquainted with the results of these experiments. It is known, for instance, in such a crude matter as the shovelling of ore that the selection of a proper shovel—one that will just allow a lift of the most advantageous weight—permits a man to handle a quantity of ore that seems altogether incredible. I believe that something like 57 to 60 tons of ore have been handled in a shift by a man when he was put on to work under specific instructions. Such a man was given the right shovel, and told how frequently to use it. The same remark applies to the handling of pig-iron. I believe that 48 tons of pig-iron have been lifted from a heap

into a truck in the course of a single shift by a man who was carefully taught to avoid fatigue. So far as colliery work is concerned, I believe that the study of fatigue would certainly lead to better and more efficient results from the labour in our pits. The ordinary colliery manager is not able to take up this work himself. Once before I made the remark that I did not consider the mining industry believed in management, and I am almost prepared to repeat that charge. If a study were made of the amount of effort put forth in doing certain jobs and tasks and a determination reached as to the proper rate at which work could be done, together with the most advantageous means of achieving a particular piece of work, I believe that good would result. On the other hand, if such a study were to be undertaken, a colliery manager would require to have one or two assistants who knew something about psychology and physiology in addition to mining. It would, of course, be monstrous to suggest to a coalmaster at the present time that assistants of that type should be got. I remember on a previous occasion urging the provision of special jobs for many of our well-trained young men, who would act as good sergeants to the colliery manager. You know that non-commissioned officers are said to be the backbone of the army. I believe we fail in the mining industry because the manager is not supported by a class of properly-trained and efficient young men. I think that the mining industry is to blame because it does not take full advantage of the talent and ability that there is ready to hand. There are many young men who would like to get their feet on the ladder and who are keen to know and do something, but who do not always get the chance. I think if the colliery manager is expected to study this side of mining, he will require the help that I have indicated. I have no doubt that the methods of measuring fatigue described by Dr. Briggs would help very considerably if an investigation of this nature were undertaken.

The Chairman: I have heard it suggested that the consideration of man as a machine implies lack of respect for the personality and individuality of the man; but, so far from that being the case, I think the contrary is true. The study of the worker, not only in regard to his physical conditions, but also in his spiritual, intellectual, and moral relations, is becoming increasingly recognized as important. When we consider man as a self-contained apparatus and reflect on the wonderful internal organism—the mechanics and chemistry of blood circulation, respiration, and digestion—with the co-ordination of the functions of all the organs, and the amazing delicacy and precision of the automatic control of the organs, we are fascinated by the wonder of it. Dr. Briggs is concerned with the external expenditure of energy, and his methods are extremely interesting. His paper seems to suggest a wider consideration of this subject. I refer, of course, to the function of management in the utilization of human labour to the best advantage—its application in such manner as will produce the maximum effect for the minimum of muscular effort. Now, in mining, is it not the case that men are very often and very widely employed upon work which is not work for human beings? Take, for example, tramming. The problem is an economic one, especially so in thin seams where in many cases there is no economic alternative, or there appears to be no economic alternative, to the use of human labour for pushing trams. On the other hand, I think there is no doubt that if workings were planned—especially in regard to the laying-off of roads and working-faces—with a special view to the utilization of mechanical appliances in tramming—

much of this low-grade manual labour might be avoided. I venture to say that if men are employed on work which can be done equally well by animals or by mechanical agencies, if men are put on jobs that make no call upon their intelligence, these men are degraded and their morale deteriorates. I think it is true that the men who are employed on such work—men whose daily toil makes no demand for mental effort—are those who are most troublesome and least amenable to reason when disturbances arise. It seems to me that economic pressure on the mining industry will emphasize the importance of the lessons to be drawn from the paper.

The further discussion of the paper was adjourned.

DISCUSSION OF MR. WILLIAM McNAUGHT'S PAPER ON "THE 'BEAM' ELECTRIC HEAD-LAMP."*

Mr. McNaught gave a practical demonstration to illustrate the handiness of the electric head-lamp.

The CHAIRMAN (Mr. Sam Mavor): Is the lamp on the market?

Mr. WILLIAM McNAUGHT (Girvan): We are just in a position to place it on the market now.

The CHAIRMAN: It has been a constant source of surprise to me that in Scotland the miners stick so rigidly to the old-fashioned flame-lamp; there has been for years the alternative of simple and greatly superior acetelene head-lamps. Visitors from elsewhere are always very much surprised—often amused—at the antiquated method of lighting which is in vogue in this country. In closed-lamp pits a safety-lamp is a most unhandy thing for a man to carry about with him at his work. He is often engaged on operations which make it imposible for him to hang up his lamp, and he must hook it to his belt or otherwise carry it about his person. Such a lamp is an obvious obstruction to freedom of movement, and an encumbrance that detracts from full application to the work on hand. Such an appliance as the "Beam" lamp seems to be a very great advantage. Does any one suggest disqualifying objections to its use?

Mr. WILLIAM McCREATH (Glasgow): Perhaps Mr. McNaught would illustrate how the lamp is affixed to the cap of the miner, and state whether any difficulty is experienced owing to the cable getting in the way?

(Mr. McNaught practically demonstrated this point by affixing the lamp to the cap, and showed that the adjustment of the cable on the back and neck of the wearer was such as to prove no encumbrance whatever).

Mr. J. BALFOUR SNEDDON (Mid-Calder): I do not think that Mr. McNaught has unduly strained the benefit of this head-lamp for shift-work. Let me repeat an experience that occurred at Dalmeny Pit as far back as ten years ago. We had a head-lamp then, which was found most useful, but we could not get it approved. For many months something like twenty men were employed in a section of the Dalmeny Pit, and they used cap-lamps in conjunction with the Jeffrey electric boring-machine.

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 82.

There was never any question with us as to the advantage of using the electric cap-lamp as against the ordinary safety-lamp. One point Mr. McNaught claims for his lamp is that it is non-spillable. The lamp at Dalmeny was, however, somewhat inclined to spill. Would Mr. McNaught state what the cost of maintenance of his lamp is likely to be, and what he proposes to charge for it?

Mr. McNaught: We claim that the cost of maintenance for this lamp will not exceed that of the best electric lamp on the market to-day. According to our methods of manufacture and construction, which differ from those of any other type of lamp, we claim that it will not be so much abused as the ordinary hand-lamp. I cannot give you exact figures just yet, because so far we have concerned ourselves chiefly with the work of getting the lamp into perfect condition so as to meet, if possible, all objections, situations, and circumstances.

The further discussion of the paper was adjourned.

A NEW METHOD OF MEASURING VENTILATING RESISTANCES, WITH SPECIAL REFERENCE TO THE OPERATION OF MINE FANS IN COMBINATION.

By DAVID PENMAN, B.Sc.

Introduction.—The purpose of this paper is two-fold, namely:—

(1) To suggest a method of measuring the ventilating resistances of mines and fans, based on analogies drawn from electric circuits.

(2) To employ this method in calculating the probable performances of duplicate ventilating plants, where two or more fans are run together in series or in parallel combination.

The problems arising in connexion with the running of fans in combination, although not new, are emerging afresh as mines become deeper and more extensive, especially in those in which the growth of the mine has outstripped the capacity of the ventilator, and an increase in the volume of air in circulation has thus become urgent. A larger air-current may be obtained in various ways—by reducing the resistance of the mine; by substituting a fan of larger capacity and giving a higher water-gauge; or by running two or more ventilators in combination. It is chiefly with the last-named method that this paper will deal, as I believe that there exists here a field for enquiry which has not yet been fully investigated.

Part I.—The Measurement of Ventilating Resistances.

That there exist many points of similarity between the flow of electricity in a conductor and the flow of air in an airway has been pointed out at sundry times by various writers; in particular, Mr. H. W. G. Halbaum has demonstrated many of the simpler relationships.* That the similarity may, with considerable advantage, be carried much farther than has yet been suggested has, so far as I am aware, not been made in any published paper on the subject. A fan ventilating the working of a mine may be compared to a dynamo propelling electricity through a circuit consisting of resistances connected, as shown in Fig. 1. *Rd* and *Ru* correspond to the upcast and downcast shafts respectively, and the resistances r_1, r_2, etc., represent the various splits or ventilating districts in the mine. The dynamo *D*, being for the purposes of the analogy a direct-current generator, creates an electromotive force, or difference of potential *E*, which causes a current *I* to flow through the circuit, as shown by the arrows. At *A* and *a* the "intake" current divides, and at b_1, b_2, and *B* the "return" currents unite.

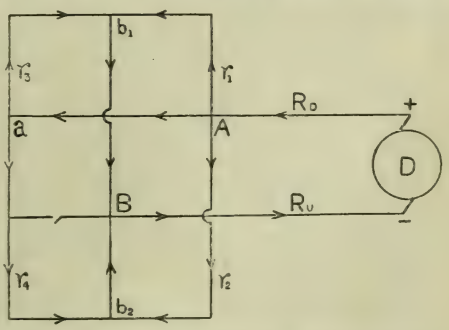


Fig. 1.—Dynamo Delivering Current to Four Parallel Circuits.

* "Analogies of Electric Currents and Mine Air Currents," *Colliery Guardian*, 1901, vol. lxxxii., pages 699 and 1213.

It is important to note, in order that the analogy may correspond closely with the case of a fan ventilating a colliery, that (*a*) the electricity must be direct current, and (*b*) the whole of the potential generated by the dynamo must be absorbed in propelling the current against the resistance of the circuit. A dynamo supplying current to motors does not here meet the case, because only a fraction of the voltage is absorbed in the conductors.

It will be seen that the conditions, as sketched in Fig. 1, resemble very closely those existing in mine ventilation. The fan situated, let us say, at the outlet of the upcast shaft, creates a depression in the fan-drift, so that there exists a difference of pressure between the fan-drift and the outer atmosphere, the pressure of the latter being the greater. The fan discharges, of course, into the atmosphere, but since an equivalent quantity of air—neglecting changes of volume due to temperature and gases given off in the mine itself—flows into the downcast shaft, the fan may be considered to work in a closed circuit in the same way as does the dynamo, especially if the dynamo is presumed to be "earthed" on the negative side. Substituting the fan, therefore, for the dynamo, and the shafts and workings for the various resistances, the analogy is complete. Now in the electric circuit (Fig. 1) there are two resistances—the resistance external to the machine and the resistance of the dynamo itself. For the network of paths in the external circuit, an equivalent resistance R, corresponding to the equivalent resistance of the mine passages, may be substituted, and the resistance of the machine r corresponds with the internal resistance of the fan.

If the electromotive force of the dynamo be E volts, the current flowing in the circuit =

$$I = \frac{E}{R + r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1),$$

R and r being measured in ohms. Or, if e_1 be the voltage at the terminals of the dynamo, then

$$I = \frac{e_1}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

$E - e_1 = e_2$, which is the voltage lost in the machine itself;

$$e_2 = Ir, \text{ or } I = \frac{e_2}{r} \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Similarly, the fan produces a total depression of H inches of water, subdivided into h_m for the mine and h_f for the fan. Let R = resistance of the mine and r = the resistance of the fan, and Q = the quantity of air flowing. Then $Q^2 = \frac{H}{R + r}$, $Q^2 = \frac{h_m}{R}$, and $Q^2 = \frac{h_f}{r}$ are the equations corresponding to (1), (2), and (3), as above. Except that in the case of the fan it is necessary to write Q^2 instead of Q — since the water-gauge or pressure is proportional to the square of the quantity—there is a close parallel between the two cases.*

In the formula for the equivalent resistances of the mine and fan, namely, $R = \frac{h_m}{Q^2}$ and $r = \frac{h_f}{Q^2}$, I am not, for the present, greatly concerned about the units in which those resistances should be measured. It might be suggested to make the unit of resistance that against which a depression of 1 inch of water would produce a circulation of 100,000

* In the case of air flowing through wastes the analogy is an exact one, since there the quantity is directly proportional to the pressure.

cubic feet of air per minute. Thus a mine in which a water-gauge of 3 inches circulated 100,000 cubic feet per minute would have an equivalent resistance of $\frac{3}{1^2} = 3$ units, while another mine in which the same water-gauge circulated only 30,000 cubic feet per minute would have an equivalent resistance of $\frac{3}{(0{\cdot}3)^2} = 33{\cdot}3$ units. This method of comparing one mine with another has the advantages over the "equivalent-opening" method of presenting the relative resistances directly instead of inversely, and of being unaffected by a co-efficient—the co-efficient of the *vena contracta* —which with air is not a constant but a variable. With regard to the latter point, it may be mentioned that Guibal and Rateau both eliminate the constant from the expressions they recommended for the "equivalent opening" of a mine, and the omission of the constant from Murgue's formula would not in any way affect it as a method of comparing mine resistances. The chief advantage of the proposed new method is that it would show at a glance the exact relationship between two or more ventilating resistances. If there are two mines the *equivalent orifices* of which are 10 square feet and 20 square feet respectively, it would seem to me to be more sensible to give the *equivalent resistance* of the former as, say, 4 units, and of the latter as 1 unit.

In the expressions given above for the resistances of the mine and fan, it is an unnecessary complication to consider questions of density, compressibility, barometric pressure, or temperature; and just as in the electric circuit the resistance can be calculated from the values of the current and pressure, without entering into the kinds of material constituting the circuit, the length or the cross-section of the various conductors, or the temperature of them, so it is practicable to estimate the resistance of a mine from measurements of air-current and water-gauge

Relation Between the "Equivalent Opening" and the Ventilating Resistance.—Let a="equivalent opening";

$$\text{then } a = \frac{0{\cdot}00039}{\sqrt{h}}\,Q. \quad \therefore \frac{1}{a^2} = \frac{h}{0{\cdot}000000152\,Q^2}, \quad \therefore \frac{1}{a^2} = cR;$$

where R is the resistance of the mine and c is some co-efficient determinable by the units in which R is to be measured. If Q is taken in hundreds of thousands, as in the proposed unit of resistance, then $a = \frac{39\,Q}{\sqrt{h}}$.

In Table I. the numerical values of equivalent orifices and the corresponding resistances in the proposed unit of resistance are compared:—

TABLE I.—COMPARISON OF NUMERICAL VALUES OF EQUIVALENT ORIFICES AND CORRESPONDING RESISTANCES IN THE PROPOSED UNIT OF RESISTANCE.

Equivalent orifice, in square feet.	Units of resistance.	Equivalent orifice, in square feet.	Units of resistance.
10	15·20	60	0·42
20	3·80	70	0·31
30	1·69	80	0·24
40	0·95	90	0·19
50	0·60	100	0·15

PART II.—THE SERIES AND PARALLEL OPERATION OF FANS.

The suggested method of estimating ventilating resistances will now be applied to the solution of problems connected with the running of mine fans in series and in parallel.

Resistances in Series and in Parallel.—In an electric circuit the equivalent resistance of a number of resistances in series is given by the formula $R = r_1 + r_2 + r_3 + \text{etc.}$ Similarly in ventilation the total resistance is the numerical sum of the several resistances. If the electrical resistances are connected in parallel, the equivalent resistance is obtained from—

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \text{etc.}$$

In ventilation, however, since the resistance as defined above is proportional to the ventilating pressure and the latter is proportional to the square of the quantity, it is necessary to write—

$$\frac{1}{\sqrt{R}} = \frac{1}{\sqrt{r_1}} + \frac{1}{\sqrt{r_2}} + \frac{1}{\sqrt{r_3}} + \text{etc.}$$

For two resistances in parallel we have—

$$\frac{1}{\sqrt{R}} = \frac{1}{\sqrt{r_1}} + \frac{1}{\sqrt{r_2}};$$

$$\text{or } R = \frac{r_1 r_2}{(\sqrt{r_1} + \sqrt{r_2})^2} = \frac{r_1 r_2}{r_1 + 2\sqrt{r_1 r_2} + r_2}.$$

If $r_1 = r_2$, this becomes—

$$R = \frac{r^2}{4r} = \frac{r}{4}.$$ *

Ventilators in Series.—Consider the electric circuit in Fig. 2, in which two dynamos D_1 and D_2, giving electromotive forces E_1 and E_2 and having internal resistances r_1 and r_2 are connected in series in a closed circuit the total resistance of which, external to the machines, is R. The current $I = \frac{E_1 + E_2}{R + r_1 + r_2}$. If D_1 only were circulating current—D_2 being cut out of the circuit—the power would be $I_1 E_1 = \frac{(E_1)^2}{R + r_1}$, and with D_2 only the power would be $I_2 E_2 = \frac{(E_2)^2}{R + r_2}$. With the two in series the power would be $I(E_1 + E_2) = \frac{(E_1 + E_2)^2}{R + r_1 + r_2}$, it being assumed that E_1 and E_2 are the same when in combination as when running separately. If $E_1 = E_2 = E$, and $r_1 = r_2$, this becomes $\frac{4E^2}{R + 2r}$, which, if r is small compared with R, is four times the power obtained from one. Of course, the prime mover driving each dynamo would have to develop twice the power it gave when operating independently in the circuit. On the other hand, if the sum of the powers developed when running separately and when running together is to be the same, the output when in series would be only twice that of each taken separately. This would mean that each dynamo would be slowed down till the electromotive force was the square-root of that given when running by itself. The voltage when in series would therefore be $\sqrt{2}E$ and the current $\sqrt{2}I$.

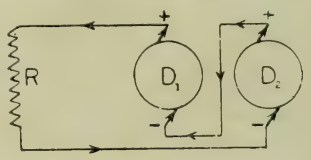


FIG. 2.—TWO IDENTICAL DYNAMOS IN SERIES.

* For resistances in parallel it might be simpler to consider *conductance*, which is the inverse of resistance; but I prefer here to adhere to the single conception throughout.

With two fans in series (Fig. 3), producing h_1 and h_2 inches of water-gauge, and having internal resistances r_1 and r_2, the resistance of the mine being R, the quantity $Q = \sqrt{\frac{h_1 + h_2}{R + r_1 + r_2}}$. With one fan only —the other out of circuit—$q_1 = \sqrt{\frac{h_1}{R + r_1}}$, and $q_2 = \sqrt{\frac{h_2}{R + r_2}}$. If $h_1 = h_2 = h$, and $r_1 = r_2 = r$, then $q_1 = q_2 = q = \sqrt{\frac{h}{R + r}}$, and $Q = \sqrt{\frac{2h}{R + 2r}}$. If r is small compared with R, $q = \sqrt{\frac{h}{R}}$ and $Q = \sqrt{\frac{2h}{R}}$—that is, the quantity produced by two fans in series under these conditions is $\sqrt{2}$ times the quantity produced by one. The necessary condition here, of course, is that the fans each produce the same total water-gauge when in combination as when operating separately. As in the electrical analogy, however, the power required by the fans in combination would be greater than the sum of the powers developed by the fans separately. The power for each fan operating separately would be hq. When in combination the power would be $\sqrt{2}\ (2hq) = 2{\cdot}828hq$, instead of $2\ hq$.

If, on the other hand, the sum of the powers developed by the fans is to be the same when running in series as when running separately, the quantity will not be increased $\sqrt{2}$, but $\sqrt[3]{2}$ times, since, as is well known, the quantity is proportional to the cube-root of the horsepower.

The difference between the two results is not always clearly indicated in mining text-books, some stating that the quantity in series is $\sqrt{2}$ times and some that it is $\sqrt[3]{2}$ times the quantity given by one fan alone.

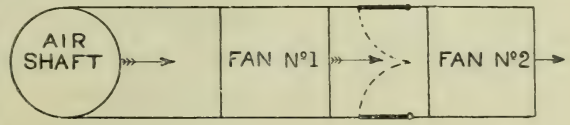


Fig. 3.—Two Identical Fans in Series.

Moreover, even for the same expenditure of power the quantity in series will not be $\sqrt[3]{2}$ times that of one fan unless the further condition that the internal resistances of the fans are small compared with the resistance of the mine is secured. Natural ventilation, which in a deep mine may aid the fan or fans considerably, may be considered as a fan the inlet of which is the entrance to the downcast shaft and its outlet the exit from the upcast shaft. Here the only resistance to be considered is the resistance of the mine itself. Thus natural ventilation under conditions which gave a water-gauge equal to the total water-gauge produced by a fan would produce a greater quantity of air in the same mine than the fan, unless the internal resistance of the fan was so small as to be negligible. The effect of natural ventilation is variable, however, and, in addition, its influence will not be the same when acting alone as when simply aiding the fan, which is the chief ventilating agent. The quantity of air in circulation when the fan was running would be considerably greater than with natural ventilation alone, even in cases where the natural effect was considerable. At Bentley Colliery,* the quantity of air circulated by the fan aided by natural ventilation was 309,530 cubic feet per minute, while with the fan standing the quantity was 200,000 cubic feet. The measurements were taken on a comparatively cold day in February, the surface temperature being 36°

* "Running Two Fans in Parallel at Bentley Colliery, and other Ventilating Problems," by Robert Clive, *Trans. Inst. M. E.*, 1919-1920, vol. lix., page 135.

Fahr. The aid given by natural ventilation on a warm day in midsummer would certainly be much less than on a cold winter's day. In order to maintain the same quantity of air in circulation, the fan would have to run slightly faster in the summer than in the winter. The effect of natural ventilation has been left entirely out of the calculations.

The quantities given by two fans in series as set out in Table II. have been calculated from the formula already given, namely :—

$$Q = \sqrt{\frac{2h}{R + 2r}}.$$

Ventilators in Parallel.—In the electrical analogy (sketched in Fig. 4), the electromotive forces are E_1 and E_2, the internal resistances r_1 and r_2, and the external resistance R. If $E_1 = E_2 = E$, the current $I = \frac{E}{R + \frac{r_1 r_2}{r_1 + r_2}}$; and if $r_1 = r_2 = r$, $I = \frac{E}{R + \frac{r}{2}}$. Under these conditions, the currents i_1 and i_2 through each machine $= \frac{1}{2}I = \frac{E}{2R + r}$. A point of importance to note here is that the potential in the circuit is exactly the same as if there was only one dynamo in the circuit, although the terminal voltage will rise slightly. If the electromotive force of one machine is less than that of the other, the potential operating in the circuit is that which is the higher. The current with only one machine operating would be $I_1 = \frac{E}{R + r}$, so that when the machines are in parallel there is an increase in the current circulated. This increase will be very great when r is great compared with R, but if r is very small compared with R, the increase in parallel will be negligible. It will be shown that this rule holds good in the case of fans.

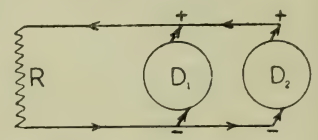


Fig. 4.—Two Identical Dynamos in Parallel.

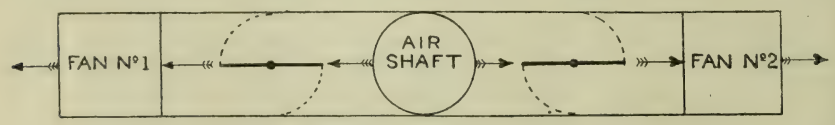


Fig. 5.—Two Identical Fans in Parallel.

The power absorbed in the circuit, if both machines were equal in every respect, would be $IE = \frac{E^2}{R + \frac{r}{2}}$, as against $\frac{E^2}{R + r}$ with only one machine running; that is, the power and current would be increased to the same extent, indicating that the efficiency of the parallel arrangement would be greater than that of a single machine.

If r_1 is greater than r_2, E_1 still being equal to E_2, i_2 will be greater than i_1; or $i_1 r_1 = i_2 r_2$.

If E_1 is less than E_2, r_1 and r_2 now being equal, i_1 will be less than i_2. When $E_1 = E_2 - i_2 r_2$, $i_1 = O$, at which point i_2 becomes I. When E_1 is less than $E_2 - i_2 r_2$, the current in r_1 is reversed in direction. It will be shown that a similar result ensues in ventilation with fans in parallel.

TABLE II.—VENTILATORS IN SERIES AND IN PARALLEL: SHOWING RELATIVE QUANTITY, POWER, AND EFFICIENCY; TOTAL WATER-GAUGE OF FANS EQUAL AND CONSTANT UNDER ALL CONDITIONS.

One fan alone.			Two similar fans in series.						Two similar fans in parallel.						Ratio: Resistance of mine / Resistance of fan.
Quantity.	Power.	Aero-dynamic efficiency-ratio.	Quantity.	Power.	Aero-dynamic efficiency-ratio.	Percentage increase of quantity.	Percentage increase of power.	Percentage decrease of efficiency.	Quantity.	Power.	Aero-dynamic efficiency-ratio.	Percentage increase of quantity.	Percentage increase of power.	Percentage increase of efficiency.	
0·577	0·577	0·33	0·632	1·204	0·20	11·0	119	40	0·816	0·816	0·66	41·0	41·0	100	0·5
0·707	0·707	0·50	0·81	1·632	0·33	15·4	131	33	0·90	0·90	0·80	27·0	27·0	60	1
0·826	0·826	0·66	1·00	2·00	0·50	21·1	142	24	0·94	0·94	0·88	14·0	14·0	33	2
0·866	0·866	0·75	1·10	2·20	0·60	27·0	154	20	0·96	0·96	0·92	11·0	11·0	23	3
0·910	0·910	0·83	1·22	2·44	0·71	34·1	168	14	0·97	0·97	0·95	6·6	6·6	14	5
0·950	0·950	0·91	1·29	2·58	0·83	35·8	172	9	0·99	0·99	0·97	4·2	4·2	6·6	10
1·000	1·000	1·00	1·414	2·83	1·00	41·4	183	0	1·00	1·00	1·00	0	0	0	Resistance of fan negligible.

TABLE III.—TEST OF WADDLE AND SIROCCO FANS RUNNING IN PARALLEL AT WELLESLEY COLLIERY, FIFESHIRE, JULY 11TH, 1920.

No. of test.	Time.	Conditions.	Waddle Fan.			Sirocco Fan.			Quantity drawn through mine.	Equivalent orifice of mine, in square feet.
			Revolutions per minute.	Water-gauge, in inches.	Quantity, in cubic feet per minute.	Revolutions per minute.	Water-gauge, in inches.	Quantity, in cubic feet per minute.		
1	9·35 a.m.	Waddle fan alone.	109	3·25	99,176	—	—	—	99,176	21·6
2	10·10 ,,	Both fans together.	120	4·00	−21,202	169	4·20	126,373	105,171	—
3	10·35 ,,	do.	135	4·75	140,583	171	4·60	−31,659	108,924	—
4	10·55 ,,	do.	132	4·60	118,242	171·5	4·60	−11,619	104,623	—
5	11·15 ,,	do.	125	4·30	67,942	172	4·25	55,584	123,526	—
6	11·35 ,,	do.	122	4·10	20,286	172	4·20	101,882	122,168	—
7	11·55 ,,	do.	118	4·00	−23,363	173	4·20	133,878	110,175	—
8	12·15 p.m.	Waddle fan alone.	125	4·20	114,310	—	—	—	114,310	21·5
9	12·35 ,,	Sirocco fan alone.	—	—	—	172	4·10	111,986	111,986	21·7

For two fans in parallel (Fig. 5), the quantity of air circulated in the mine will be $Q_1 = \sqrt{\frac{h}{R + r_1}}$, as compared with $Q = \sqrt{\frac{h}{R + r}}$ for one fan operating alone. Applying the method of compounding resistances in parallel, $r_1 = \frac{1}{4}r$, if $r_1 = r_2 = r$. The quantity will be increased to an extent depending upon the ratio of R to r. Further, as in the case of the ventilators in series, the increase will be different, depending upon whether the conditions are such as to maintain the water-gauges or the horsepower at a constant value. In Table II. the quantities circulated by two fans in parallel, as compared with one fan, are set out for various ratios of $\frac{R}{r}$. The condition assumed is that the water-gauges produced by each fan are the same when running in combination as when operating separately.

The results given in Table II. are plotted graphically in Fig. 6, in which it is seen that if increase of quantity is the prime consideration, better results are obtained by running fans in series than in parallel.

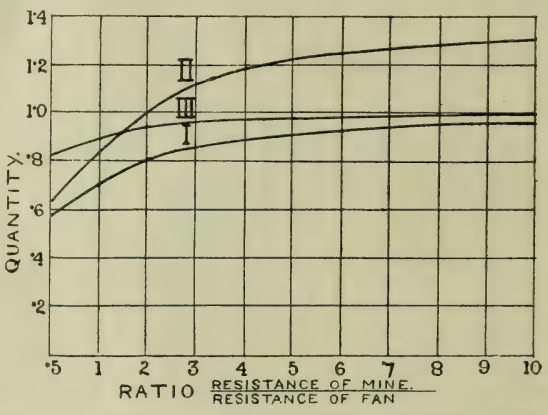


Fig. 6.—Quantity of Air Delivered by Mine Fans under Different Conditions: (I) Single Fan; (II) Two Identical Fans in Series; (III) Two Identical Fans in Parallel.

Aero-dynamic Efficiency - ratio.—In the calculations and graphs efficiencies are calculated in the following way:—

Aero-dynamic efficiency-ratio of a single-fan system

$$= \frac{\text{Resistance of the mine}}{\text{Resistance of mine + resistance of fan}} = \frac{R}{R + r};$$

Aero-dynamic efficiency-ratio of a system ventilated by two identical fans in series $= \frac{R}{R + 2r}$;

Aero-dynamic efficiency-ratio of a system ventilated by two identical fans in parallel $= \frac{R}{R + \frac{r}{4}}$.

In all three cases if r is small compared with R, the ratio approximates to 100 per cent. This does not mean, of course, that the actual efficiency will have that value, since the mechanical efficiency of the engine or motor driving the fan and the frictional and other losses in the fan itself must affect materially the overall efficiency.

I have chosen the term "aero-dynamic efficiency-ratio" to distinguish it from the real efficiency of the ventilating system. As expressed above, the aero-dynamic efficiency is numerically equal to the air-resistance of the mine divided by the total air-resistance of the ventilating system. It might also be expressed as the ratio of the power expended in the mine itself to the total aero-dynamic power expended both in the mine and

the fan-passages. It would not be easy to say, even approximately, what is likely to be the relation between the aero-dynamic ratio and the efficiency of the whole plant. Much would depend upon the method of driving the fan, the condition of the engine or motor, and the loading. Obviously, however, the real efficiency would in every case be *less* than that shown in Table I.

The curves in Fig. 7 are plotted from the results in Table II., and show very strikingly that the parallel arrangement increases the efficiency of the ventilating system, especially if the resistance of the fan equals or nearly equals that of the mine, whereas on the other hand the series combination makes for a lowered efficiency.

Distribution of Quantity with Two Similar Fans in Parallel but Running at Different Speeds.—When two similar fans run in parallel, it has been shown that the quantity of air delivered by the two will be greater than that given by one, provided that the resistance of the fan is not negligible. Consider now what would happen if the speed of one fan were gradually reduced. We may here again have recourse to the electrical analogy. Imagine the dynamo D_1 to run at constant speed and maintain an electromotive force E_1, and the dynamo D_2—which gives the same electromotive force at the same speed—to be slowed down. The electromotive force of D_2 will decrease according to some power of the speed, depending, amongst other things, on the method of excitation. As a result of this fall of electromotive force, the current through D_2 will be less and the current through D_1 greater than when both give the same electromotive force. Eventually a point will be reached when no current at all will flow through D_2 and all the current will pass through D_1. Suppose the current at this stage flowing through D_1 to be I; then the voltage drop in D_1 is $I_1 r_1$, and the terminal voltage of D_1 is $E_1 - I_1 r_1 = e_1$. Now since no current flows through D_2, its electromotive force must be equal and opposite to the terminal voltage of D_1; that is, $E_2 = e_1$. Under those conditions the voltage produced in D_2 is just sufficient to prevent reversal of current in it. It should be noted that the value of the current flowing through D_1 is the same as if the machine D_2 were cut out of the circuit and D_1 were running alone. Thus when the electromotive force of $D_2 = e_1$, the effect is the same as if D_2 did not exist at all. Any further fall of speed of D_2 would cause current to pass through the armature in the opposite direction to that in which it delivered current as a dynamo; in electrical parlance, D_2 would commence to motor.

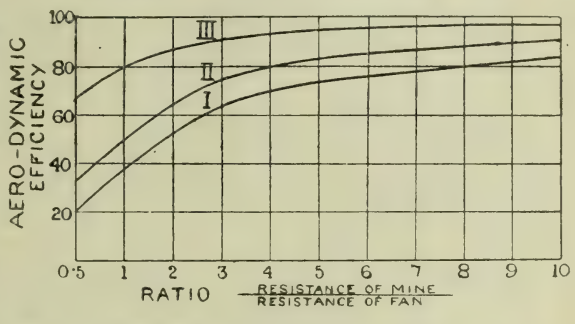


Fig 7.—Efficency of Ventilating Systems: (I) Two Identical Fans in Series; (II) Single Fan; (III) Two Identical Fans in Parallel.

It will be evident that a somewhat similar condition obtains when two fans run in parallel. As one fan is slowed down, the depression caused by it falls off as the square of the reduction of speed. Thus less air is drawn through it and more air passes through the other fan.

Let the water-gauge in the fan-drift with only one fan running be h, and let the total water-gauges of each fan when running at the same

speed be h_{f1} and h_{f2} respectively. Imagine h_{f1} to be maintained constant and h_{f2} to fall slowly as the speed of that fan is reduced. When both are running at the same speed in parallel, the water-gauge in the fan-drift will be slightly greater than h, for reasons already explained; but as one fan is slowed down, h will fall slowly, until eventually when no air is passing through the slower-running fan, and all through the other, h will resume the value it had when only one fan was running. At this point, reasoning from the electrical parallel, the total depression produced by the slow fan will be equal to h, the water-gauge in the fan-drift. The depression produced by that fan will now be just enough to prevent the other fan from sucking air through it from the outside atmosphere. Any further fall of speed would result in air being drawn through the fan in the direction opposite to that in which it delivers air.

The graphs in Fig. 8 show the distribution of the air in two similar

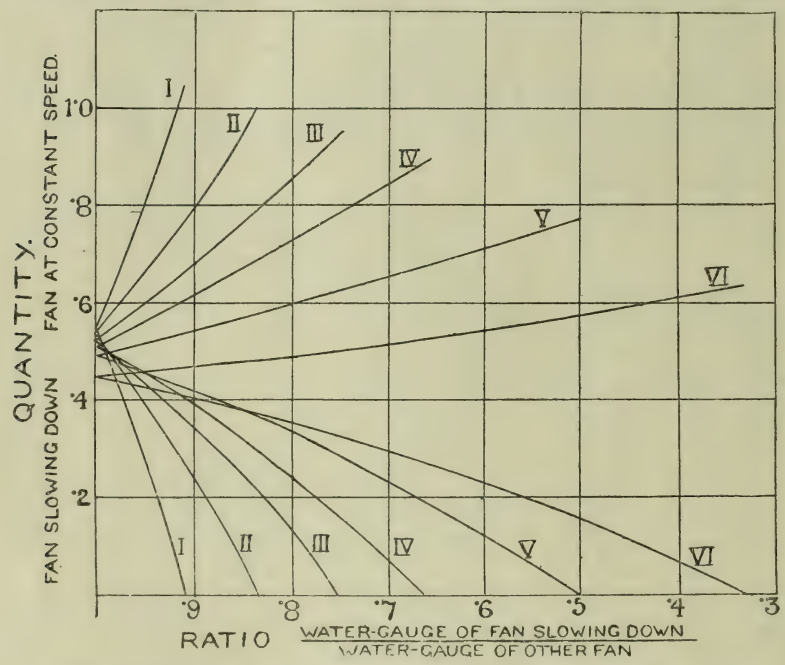


FIG. 8.—DISTRIBUTION OF QUANTITY OF AIR BETWEEN TWO FANS RUNNING TOGETHER IN PARALLEL.

fans in parallel, one of which is supposed to be slowing down. Quantity is plotted vertically and the ratio $\frac{\text{water-gauge of fan slowing down}}{\text{water-gauge of fan at constant speed}}$ is plotted horizontally.

Six different pairs of curves are plotted, in order to see the effect of the internal resistance of the ventilator on the rate at which the re-distribution of the quantity will take place. For example, when the internal resistance of each fan is one-tenth of the resistance of the mine, the fan slowing down will cease to deliver any air at all when its total water-gauge is 0·91 of the water-gauge produced by the fan running at constant speed. On the other hand, if the internal resistance of each fan were twice the resistance of the mine—a highly exaggerated case—the slower fan would continue to deliver air until its water-gauge was as low as 0·333 of that of the other fan. The former case represents fairly common practice at collieries in this

country, and it will be seen that the transference of volume from the fan which is slowing down to the other is very rapid. The curves are very nearly straight lines, and when they are re-plotted to a speed base, as in Fig. 9, they become still more nearly straight. All the points on the curves are calculated from purely theoretical considerations, and on the assumption that the fans have radial blades—that is, that the water-gauge produced by the fan is not affected by the quantity of air passing through the fan, but is constant for a given speed whatever the circulation of air through it. The method of calculation is given in an appendix to this paper.

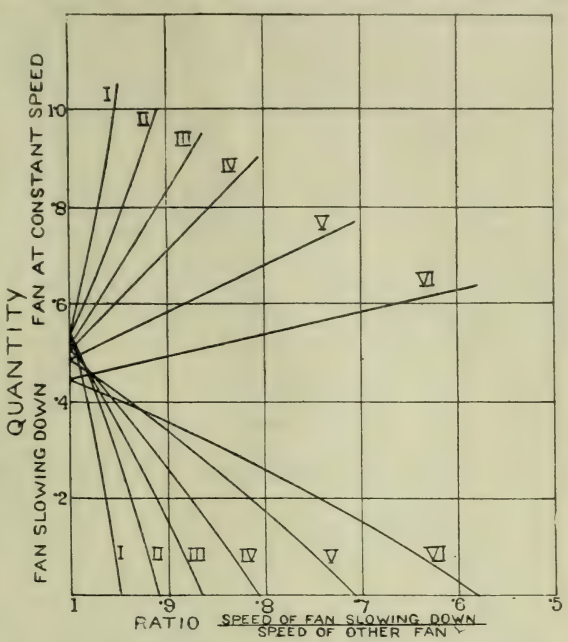


FIG 9.—DISTRIBUTION OF QUANTITY OF AIR BETWEEN TWO FANS RUNNING TOGETHER IN PARALLEL.

Effect of Shape of Blades of Ventilator.—It is well known that the depression produced by a fan depends not only upon the peripheral speed, but also upon the angle that the blades make with the tangent to the periphery at the point where the blade terminates.*

REFERENCE TO FIGS. 8 AND 9.

No. of curve.	Ratio : $\frac{\text{Resistance of mine}}{\text{Resistance of fan.}}$
I.	10
II.	5
III.	3
IV.	2
V.	1
VI.	0·5

Let h=theoretical water-gauge, in inches.
v=peripheral velocity, in feet per second.
u=radial velocity, in feet per second.
α=angle blades are turned backwards or forwards.
Then the equations giving the theoretical water-gauge are :—

(1) For fans with radial blades, $h = \frac{v^2}{g} \times 0{\cdot}015$.

(2) For fans with blades curved backwards, $h = \frac{v(v - u\cos\alpha)}{g} \times 0{\cdot}015$ (for example, Waddle and Walker fans).

(3) For fans with blades curved forwards, $h = \frac{v(v + u\cos\alpha)}{g} \times 0{\cdot}015$ (for example, Sirocco, Keith, and Ser fans).

* "The Principle of Design of Ventilating Fans," by Henry Briggs, *Colliery Managers' Pocket Book*, 1909, page 316.

In a fan with radial blades or blades which are radial at the tips, the theoretical water-gauge depends only on the peripheral speed, and is not at all affected by the quantity of air delivered by the fan. For this reason the static water-gauge in the fan-drift of such a fan is greatest when the fan-drift is completely shut off. Fans with blades curved backwards or forwards behave differently, as the theoretical depression they are capable of producing is not independent of the quantity of air passing through the fan. The effect of increase of quantity in a fan with blades trending backwards is to reduce the theoretical depression, and in the case of a fan with forward-curved blades the opposite effect is produced. The static depression in the fan-drift of the latter type of fan will not be a maximum when the fan-drift is entirely closed. As the fan-drift is gradually opened, the static water-gauge will rise slightly, due to the added forward velocity of the air as it leaves the fan-tips. The greater the quantity of air delivered by the fan, the greater will be the theoretical water-gauge produced by the fan. As against this, the

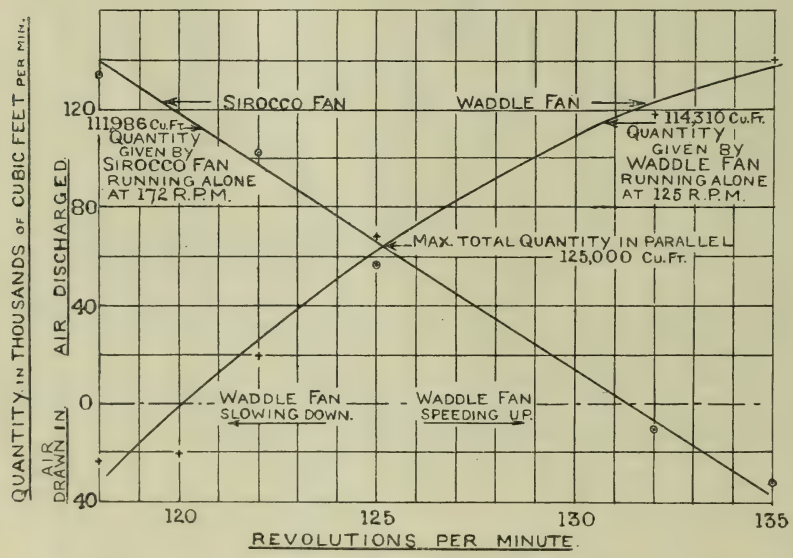


Fig. 10.—Distribution of Quantity of Air between Two Fans Running Together in Parallel at Wellesley Colliery.

greater the volume of air, the greater will be the proportion of the water-gauge lost in the fan itself. Eventually the resistance of the fan will wipe out the influence of the forward blades, and the static water-gauge in the fan-drift will commence to decrease.

On the other hand, the water-gauge produced by a fan with backward curved blades will not rise at all as the fan-drift is opened, but will continue to fall away gradually.

The fan with radial blades will occupy a position somewhere in between the other two types of fans.

The fan with blades curved forwards may be likened to a direct-current dynamo with compound winding, the fan with backward blades to a shunt-wound dynamo, and the radially-bladed fan to a dynamo separately excited with constant current.

With regard to the points primarily at issue in this paper, it may be said that fans with forward-curved vanes are not likely to run so satisfactorily in combination as fans with backward-curved blades. The

reason for this lies in the fact that any increase in the quantity of air passing through fans of the former type will result in a higher water-gauge at the same speed, whereas in the latter form the water-gauge would tend to diminish. If the fans were running in series, little or no difficulty would arise, since overloading could be prevented by a slight fall in speed; but if the combination were the parallel arrangement, the matter would not be quite so easy. In the experiment at the Wellesley Colliery, shortly to be described, we have the case of a fan with forward blades and one with backward blades running at speeeds at which they share the air equally. Now suppose the speed of the Waddle fan—as in the experiment—to be reduced: this would cause a larger quantity to flow through the Sirocco fan and a smaller quantity to flow through the Waddle fan. The total

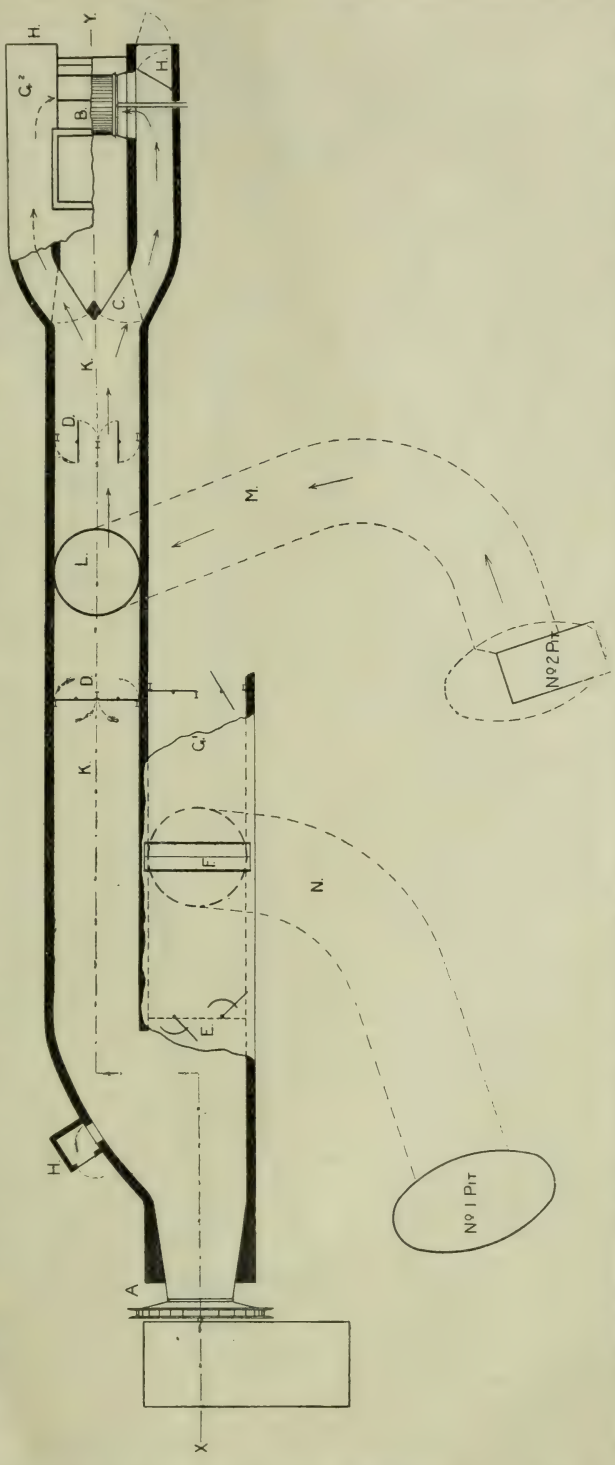


FIG. 11.—PLAN SHOWING ARRANGEMENT OF DUPLICATE FANS AT WELLESLEY COLLIERY. ROOF OF FAN-DRIFTS REMOVED EXCEPT AT G^1 AND G^2; SIROCCO DOUBLE-INLET FAN SHOWN EXHAUSTING. SCALE, 32 FEET TO 1 INCH. THE REFERENCE LETTERS ON FIG. 12 APPLY ALSO TO FIG. 11.

water-gauge produced by the Sirocco fan, even though its speed was unchanged, would now be greater, since the depression produced by a fan of that type depends not only on the speed but also on the delivery of air. Such a fan would, therefore, tend to overload itself more rapidly than would the other type if the positions were reversed, for if the Waddle were the fan dealing with the increased quantity — assuming now that its speed was kept constant while the speed of the other was reduced — its depression would diminish, which would naturally tend to relieve the load upon it.

This, I believe, is to some extent shown by the graphs in Fig. 10, for while the quantity line for the Sirocco fan is straight, indicating an increase of quantity sustained by a rising water-gauge, the same graph for the Waddle fan bends downwards, showing a falling away as compared with the Sirocco fan.

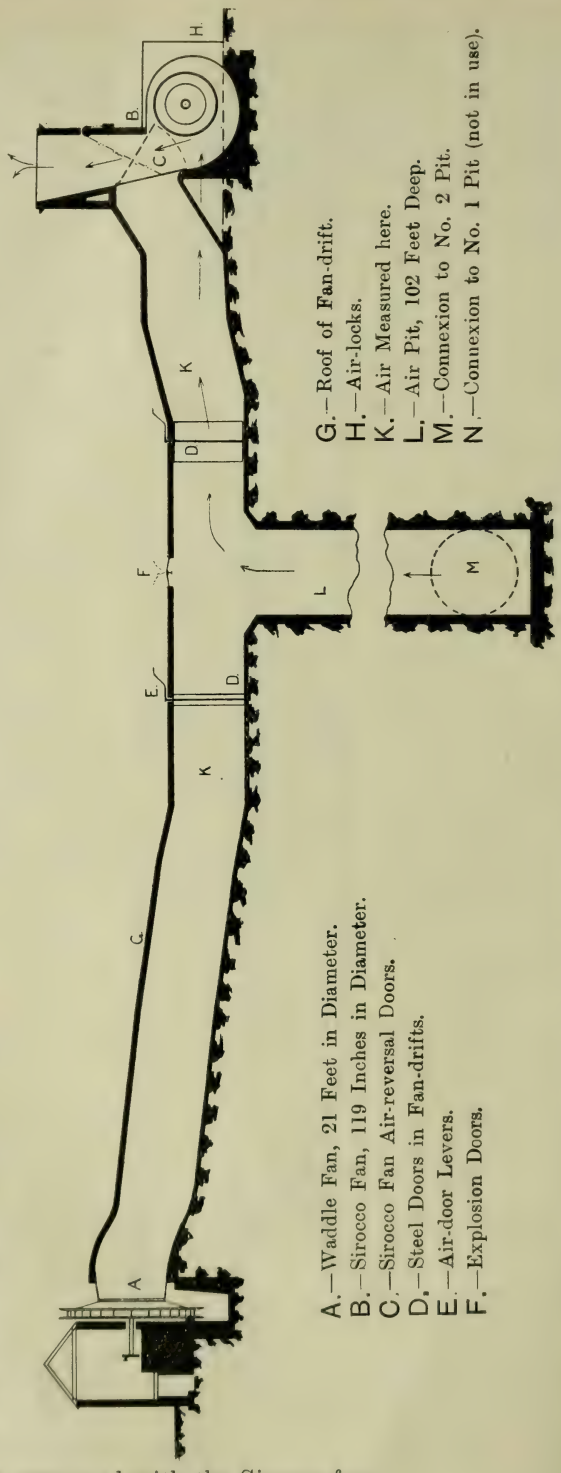


Fig. 12.—Section on Line X-Y of Fig. 11. Scale, 32 Feet to 1 Inch.

Test of Two Fans in Parallel at Wellesley Colliery.—Through the

kindness of Mr. Richard Kirkby and Mr. David Beveridge, of the Wemyss Coal Company, Limited, I was able to carry out at their Wellesley Colliery a test which gave extremely interesting results.* Duplicate fans are installed at this colliery. One of them is a Waddle fan, 21 feet in diameter, and the other is a double-inlet Sirocco fan, 119 inches in diameter and 7 feet wide. Both fans have a rated capacity of 200,000 cubic feet per minute at a water-gauge of 4 inches.

The fans are placed to right and to left of a 14-foot diameter vertical air-shaft which connects with the upcast shaft at a point 102 feet below the surface. A separate fan-drift leads from the air-shaft to either fan, as shown in Figs. 11 and 12.†

Either fan can be placed in connexion with the mine, or be completely shut off from it by means of swing doors operated from the roof of the fan-drift on the outside. It is usual to run the fans separately and alternatively for a month at a time. The Waddle fan is driven by a tandem-compound engine and has no governor, the speed being varied when necessary by adjusting the throttle-valve. The usual speed is somewhere about 110 revolutions per minute, at which speed the fan under present conditions gives approximately 100,000 cubic feet per minute. The Sirocco fan is driven by a compound condensing Bellis-&-Morcom vertical engine. This engine is governed, and maintains a speed of about 170 revolutions per minute, within a variation of approximately 1 per cent. over a considerable range of loading. At this speed the fan gives approximately 110,000 cubic feet per minute.

It should be noted that at present both fans are working at only about half of their rated capacity. As the colliery develops—the mine is comparatively new—the quantity of air circulated will in all probability greatly increase.

The aim of the test was two-fold—first, to ascertain what increase of quantity was obtainable by running the two fans together in parallel, and, secondly, to see the effect of variation of speed on the distribution of the air between the two fans. For several reasons it was decided not to take measurements of the horsepower of the engines, but to confine attention to quantity, water-gauge, and speed.

The observers worked in pairs, two in each fan-house to record the speed of the engine and the water-gauge, and two in each fan-drift to measure the velocity of the air. Every test was taken over a period of five minutes, so as to obtain a good average value from the readings. During the five-minute test period the water-gauges were read every half-minute and the total revolutions of the engines counted, and from this data the average value was obtained. The method of measuring the velocity was to move the anemometer slowly and steadily along lines parallel to the floor of the drift at vertical intervals of about 1 foot. This method, I consider, gives a better average value than that in which the instrument is held stationary for short periods in predetermined positions. The positions chosen for velocity measurements were about 20 feet on either side of the vertical air-shaft, clear of the air-doors, and in straight portions of the fan-drifts, so that eddies would be at a minimum. At the measuring points the drift leading to the Waddle fan was $11\frac{1}{2}$ feet high by 13 feet 11 inches wide, and the drift leading to the Sirocco fan $12\frac{1}{4}$ feet high by $13\frac{3}{4}$ feet wide. Both anemometers were mounted on

* I should like to record my appreciation of the assistance given by Mr. J. Brown, the Manager of the colliery.

† I am indebted to Mr. J. M. Bell, Chief Surveyor to the Wemyss Coal Company, Limited, for the drawings for these two figures.

a long stick or rod, so as to enable the instrument to be held close to the roof as well as out from the body. The following is a brief record of the tests taken :—

Test No. 1.—Waddle fan alone drawing air from the mine; doors in Sirocco fan-drift closed. Speed of Waddle fan, 109 revolutions per minute; air drawn from mine, 99,176 cubic feet per minute; water-gauge, 3·25 inches.

Test No. 2.—Both fans running. Speeds: Sirocco fan, 169 revolutions per minute; Waddle fan, 120 revolutions per minute;* quantities: Sirocco fan, 126,373 cubic feet; Waddle fan, −21,202 cubic feet;† air drawn from mine, 105,171 cubic feet; water-gauge, 4·2 inches and 4·0 inches respectively.

Test No. 3.—Both fans running. Speeds: Sirocco fan, 171 revolutions per minute; Waddle fan, 135 revolutions per minute; quantities: Sirocco fan, −31,659 cubic feet; Waddle fan, 140,583 cubic feet; air drawn from mine, 108,924 cubic feet; water-gauge, 4·6 inches and 4·75 inches respectively.

Test No. 4.—Both fans running. Speeds: Sirocco fan, 171·5 revolutions per minute; Waddle fan, 132 revolutions per minute; quantities: Sirocco fan, −11,619 cubic feet; Waddle fan, 118,242 cubic feet; air drawn from mine, 104,623 cubic feet; water-gauge, 4·6 inches in both fan-drifts.

Test No. 5.—Both fans running. Speeds: Sirocco fan, 172 revolutions per minute; Waddle fan, 125 revolutions per minute; quantities: Sirocco fan, 55,584 cubic feet; Waddle fan, 67,942 cubic feet; air drawn from mine, 123,526 cubic feet; water-gauge, 4·25 inches and 4·3 inches respectively.

Test No. 6.—Both fans running. Speeds: Sirocco fan, 172 revolutions per minute; Waddle fan, 122 revolutions per minute; quantities: Sirocco fan, 101,882 cubic feet; Waddle fan, 20,286 cubic feet; air drawn from mine, 122,168 cubic feet; water-gauge, 4·2 inches and 4·10 inches respectively.

Test No. 7.—Both fans running. Speeds: Sirocco fan, 173 revolutions per minute; Waddle fan, 118 revolutions per minute; quantities: Sirocco fan, 133,878 cubic feet; Waddle fan, −23,363 cubic feet; air drawn from mine, 110,515 cubic feet; water-gauge, 4·2 inches and 4·0 inches respectively.

Test No. 8.—Waddle fan alone drawing air from mine at 125 revolutions per minute;‡ quantity of air, 114,310 cubic feet; water-gauge, 4·2 inches.

Test No. 9.—Sirocco fan alone drawing air from mine at 172 revolutions per minute; quantity of air, 111,986 cubic feet; water-gauge, 4·1 inches.

* It was found on opening the doors in the Sirocco fan-drift that the Waddle fan, instead of delivering air, was having air sucked through it in the reverse direction. The speed of the Waddle fan was accordingly increased to 120 revolutions per minute. Even at this speed the air was reversed in the Waddle fan. It was decided, however, to take measurements.

† The minus sign indicates air drawn through the fan in the reversed direction.

‡ This speed was chosen because it appeared from the previous tests that that was the speed at which the fan would share the air nearly equally with the Sirocco fan at 172 revolutions per minute.

The results are shown in tabular form in Table III.; and on the assumption of constant speed in the case of the Sirocco fan, two graphs have been plotted in Fig. 12, showing the probable quantities given by the two fans operating in parallel when the speed of the Waddle fan is varied from 118 revolutions per minute to 135 revolutions per minute. The graphs intersect when the speed of the Waddle fan is approximately 125 revolutions, and at this point each fan delivers rather more than 62,000 cubic feet per minute, making approximately 125,000 cubic feet together. As the Waddle fan slows down, the quantity delivered by it rapidly decreases, until at a speed of 120 revolutions per minute the Waddle fan delivers no air at all, the total depression being just sufficient to balance the depression in the fan-drift. At this point the quantity delivered by the Sirocco fan is somewhere between 110,000 and 120,000 cubic feet, and approximates to that given by that fan running alone. Thus the Waddle fan ceases to deliver air when its speed falls about 4 per cent. below that at which it shares the air equally with the other fan.

On the other hand, when the speed of the Waddle fan is increased to slightly over 131 revolutions per minute, the Sirocco fan has ceased to deliver air and the Waddle fan discharges slightly over 115,000 cubic feet per minute, approximating to that delivered by it when running alone. Thus the Waddle fan would commence to reverse the air in its companion when its speed was increased by about 5 per cent. above that at which it took one-half of the total delivery of air.

When the speed of the Waddle fan is more than 4 per cent. under the speed at which it takes half the air, the flow of air is reversed in it; and when it runs at more than 5 per cent. above that speed, the air is reversed in the Sirocco fan.

It will be seen that this performance corresponds with that obtained from purely theoretical considerations in Fig. 8, the conditions pertaining to which are that the resistance of the fan is one-tenth the resistance of the mine.

It is probable that many of the mine fans in this country are operating under conditions approximating to those obtaining in the colliery at which the tests were made; if so, it is clear that in most cases not only is the gain of quantity small by parallel operation, but a very small variation of speed of one of the fans will cause a reversal of the air in one or other of the fans.

Neither of the fans is working, however, under conditions which would enable them to attain a maximum efficiency.

From particulars supplied to me by the makers of the fans, it appears that the Sirocco fan is designed to work on a mine having an equivalent orifice of 56·67 square feet, and the Waddle fan for working on mine equivalent orifices of 45 to 75 square feet. As the mine develops, therefore, and its equivalent orifice increases—or, as I would prefer to express it, its equivalent ventilating resistance decreases—the conditions will become more favourable, not only to each fan running alone, but to the two operating in parallel combination.*

At present the resistance of the mine is equivalent to an opening of 21·6 square feet. It should be pointed out that although in this test a very slight variation in the speed of one of the fans caused a considerable volume to be drawn through the slower-running fan in the reverse direction, yet the quantity of air drawn from the mine was not greatly

* It should be mentioned that the two fans are not installed with the intention of running them in parallel, but simply as duplicate fans.

affected. For instance, when as much as 31,659 cubic feet of air per minute were being drawn through the Sirocco fan, 108,824 cubic feet were drawn out of the mine itself; and throughout the series of tests—with the single exception of the first—the quantity taken from the mine never fell to 100,000 cubic feet per minute.

Another matter worthy of note is that when the conditions were such that one of the fans was delivering little or no air, a sort of "hunting" action took place in that fan, the air flowing at one period in the normal direction and at another in the reverse direction. The reversal of the air would tend probably to speed up or "motor" the fan, which effect would disappear when the fan recommenced delivery of air.

Comparison of Results Obtained at Three Different Collieries.—In Table IV. I have compared the results obtained from experiments on the parallel running of fans at three different collieries. All the figures are experimental results, except those for the orifices of passage of the various fans. Those have been derived from purely theoretical considerations and on the assumption that both fans in each set have the same internal resistance. For example, at St. John's Colliery, Normanton, Mr. E. Brown obtained an increase in quantity of air of 21 per cent. with parallel operation. Referring to Table II., it will be seen that this increase of quantity is got when the resistance of the mine is greater than but not more than twice the resistance of the fan, from which it is assumed that the orifice of passage of each of the Guibal fans in use at that colliery is or was somewhere about 50 square feet. Again, the increase of quantity at Bentley Colliery was 15 per cent., which, from Table II., agrees with an orifice of passage of about 100 square feet.

I asked the makers of both the Sirocco and the Waddle fans in use at Wellesley Colliery if they could supply the orifices of passage of the fans, but neither was in a position to do so, and so far I have not had an opportunity to obtain the values myself. It would appear, however, from Table II. that the resistance of each fan corresponds to an "opening" of about 70 square feet.

I am fully aware that this method of estimating the orifice of passage of the fan is somewhat haphazard, and that the actual values may differ considerably from those given, but it is the only one available at the moment. Moveover, they agree—*prima facie*, at any rate—with the experimental results.

It should be pointed out that makers of fans attach little importance to what is termed the "orifice of passage" of a fan. It seldom or never enters into the calculations made when designing the fan for a given duty. This is not as it should be, but in the present state of our knowledge of fan resistances their attitude is perhaps justifiable.

Part III.—Conclusions.

The following are the conclusions arrived at:—

(1) The advantage to be gained by two or more fans in series or in parallel depends chiefly on the relation existing between the resistance of the fans and that of the mine.

(2) Unless the resistance of the fan is small compared with that of the mine, the operation of two fans in series will result in a greatly lowered efficiency.

(3) Unless the resistance of the fan is at least one-third of the resistance of the mine, the advantage of running two fans in parallel is small.

TABLE IV.—COMPARISON OF RESULTS OBTAINED BY RUNNING FANS IN PARALLEL UNDER DIFFERENT INTERNAL AND EXTERNAL RESISTANCES.

Year of test.	Colliery.	Equivalent orifice of colliery, in square feet.	Equivalent resistance.	Observer.	Type and size of fan.	Probable orifice of passage of fan, in square feet.	Probable equivalent resistance	Ratio: Resistance of mine / Resistance of fan.	Water-gauge (measured), in inches.	Quantity given by one fan alone (measured)	Quantity given by two fans in parallel (measured).	Percentage increase of quantity by parallel operation.
1892	St. John's * (Yorkshire).	40·2	0·95	E. Brown.	Two Guibal fans, each 24 by 8 feet.	50	0·60	1·5	1·60	112,528	—	—
						—	—	—	1·25	114,207	—	—
					Single inlet.	—	—	—	2·00	—	139,147	21·10
1918	Bentley † (Yorkshire).	78	0·25	R. Clive.	(1) Capell, 16 by 5½ feet.	100	0·13	2	2·7	328,187	—	—
						—	—	—	2·6	322,573	—	—
					(2) Capell, 17 by 6 feet. Both single inlet.	—	—	—	3·65	—	375,144	15·3
1920	Wellesley (Fifeshire).	21·6	3·10	D. Penman.	(1) Waddle, 21 feet in diameter.	70	0·31	10	4·20	114,310	—	—
						—	—	—	4·10	111,986	—	—
					(2) Sirocco, 119 inches by 7 feet.	—	—	—	4·30	—	123,526	9·3

* *Trans. Inst. M. E.*, 1892-1893, vol. iv., page 532.

† *Ibid.*, 1919-1920, vol. lix., page 135.

(4) If the resistance of the fan is small compared with that of the mine, not only will the increase of quantity by parallel operation be small, but a slight reduction or increase in the speed of one of the fans over the other will result in the air being reversed in that fan which runs at the slower speed.

(5) If increase of quantity is the sole desideratum, better results will in most cases be obtained by combining the fans in series than by running them in parallel.

(6) The increase of quantity obtained by running two similar fans in series at the same speed at which they would run singly would in most cases be approximately 35 per cent.

(7) The increase of quantity obtained by running two similar fans in parallel would range from 5 to 15 per cent. in the majority of mines in Great Britain.

(8) The satisfactory running of two fans in parallel can best be accomplished through the medium of synchronous electric motors.

(9) If two fans are running in parallel and the speed of one should fall to any extent, the other fan may become dangerously overloaded, unless there is a large margin of power available in the motor or engine driving it.

APPENDIX.—Method of Calculating Points on Graphs in Figs. 8 and 9.

The method of calculating the points on the graphs in Figs. 8 and 9 is as follows:—

Let R = equivalent resistance of the mine.

r_1 and r_2 = equivalent resistance of the two fans respectively.

r_1 = equivalent resistance of the fans when operating in parellel.

q and q^1 = quantities with one fan and two fans respectively.

Suppose r_1 and r_2 to be the same and to be one-fifth of R, then when one fan only is running, the total equivalent ventilating resistance is $R + r_1 = R + \frac{1}{5} R = \frac{6}{5} R$.

When the two fans are operating in parallel and sharing the air equally, the combined resistance of the two is one-fourth of the resistance of one of them (see page 42).

Thus $r_1 = \frac{1}{4} r_1 = \frac{1}{20} R$.

The total equivalent ventilating resistance is, therefore, now $R + \frac{1}{20} R = \frac{21}{20} R$.

From the equation $q = \sqrt{\frac{h}{R}}$, we have $q \propto \sqrt{\frac{1}{R}}$, since h is constant;

$$q^1 = q \times \sqrt{\frac{\frac{6}{5}}{\frac{21}{20}}} = q \times \sqrt{\frac{24}{21}} = 1{\cdot}07q.$$

Thus the quantity passing through each fan will now be $0{\cdot}535q$. For this condition the total water-gauge produced by the two fans must be the same if the resistances are equal.

Take next the circumstances in which the quantity passing through one fan is n times that passing through the other (call the lesser quantity x cubic feet), then one fan gives x and the other gives nx cubic feet.

On the assumption that the ventilating resistance in the fan is proportional to the square of the quantity passing through it, the resistance in one fan will be kx^2 and in the other kn^2x^2. Combining those resistances and taking $k = 1$, we get (see page 42) the combined equivalent resistance of the two fans $= \frac{x^2 \times n^2x^2}{x^2 + 2\sqrt{x^2n^2x^2} + n^2x^2}$.

Taking $x = 1$, this reduces to $\frac{n^2}{1 + 2\sqrt{n^2} + n^2}$.

Let $n = 2$, then $\frac{n^2}{1 + 2\sqrt{n^2} + n^2} = \frac{4}{9}$.

That is, the combined equivalent resistance is now four-ninths of that of one of the fans. Thus for the condition that one fan passes twice as much air as the other the combined resistance r' is $\frac{4}{9} \times \frac{1}{5} = \frac{4}{45} R$.

The total equivalent resistance is, therefore, $\frac{4}{45} R + R = \frac{49}{45} R$.

Consequently, $q_1 = q \times \sqrt{\frac{\frac{6}{5}}{\frac{49}{45}}} = q \times \sqrt{\frac{54}{49}} = 1{\cdot}05q$.

One fan takes $0{\cdot}35q$ and the other $0{\cdot}7q$.

Assuming that the fan taking the larger quantity has been kept running at constant speed, the other must have been slowed down. Of the total water-gauge 45 49ths is used to send the air through the mine and4/49ths to send the air along the parallel path through the two fans. But since the quantity passing through one of the fans is only half that passing through the other, the water-gauge absorbed in it will only be one-quarter of that absorbed in the fan passing the greater quantity. Thus one of the fans has been slowed down until its total water-gauge is $\frac{1}{49} + \frac{45}{49}$, or $\frac{46}{49}$ths of the water-gauge produced by the fan at constant speed. In this way another point on each of the curves II. (Figs. 8 and 9) has been obtained and similarly for other points on the graphs. The points from which the other pairs of graphs are plotted were calculated in the same way.

The quantity of air delivered by one fan the resistance of which is one-fifth of that of the mine is taken as unity, and all quantities are reduced throughout to this as a standard.

Mr. Joseph Parker (Cowdenbeath): I congratulate the author on the very clear manner in which by reasoning and experiment he has shown the actions of ventilating fans in series and in parallel. The curves attached to the paper reveal these actions in a very convincing manner.

There is really nothing new, however, in the analogies he draws between the electric currents produced by direct-current generators and the air-currents produced by fans. The proposed unit for estimating the resistance of a mine is likewise not new, and has been suggested in one form or another by numerous writers. Starting with Atkinson's formula:—$pa = ksv^2$, we may write $pa^3 = ksv^2a^2 = ksQ^2 \therefore Q^2 \div p) = (a^3 \div ks)$.

The right-hand side of this equation contains only quantities belonging to the airway or mine (the co-efficient of friction, the extent of the rubbing surface, and the cross-sectional area), and measures the opening or freedom of passage of the airway or mine to the passage of the air-current. It is very much easier to calculate this opening for any particular mine by observing the quantity passing and the pressure than by attempting to evaluate the right-hand member of this equation. The ratio Q^2/p when multiplied by a constant has been well known under the term "equivalent orifice" since first introduced by Murgue. The notion of the term is analogous to that of conductance in electrical circuits. The inverse notion to conductance is resistance, and by inversion we have $h \div Q^2 = ks \div a^3$, so that the ratio $h \div Q^2$ measures the resistance of the mine or airway.

Both the notion of resistance and that of conductance have been freely used in the past, and it is preferable that *each* should be used in the proper place. Mr. Penman himself admits this when he states that "For resistances in parallel it *might* be simpler to consider conductance,

which is the inverse of resistance." To be correct, he should change that *might* into *would*, for while the term "resistance" is decidedly preferable where resistances in series are concerned, since the resultant resistance is obtained by simple addition of the resistances, the same preference for the like reason belongs decidedly to the term *conductance* where the circuits are in parallel. Even when it is desired to determine the joint resistance of a number of circuits in parallel, it will be found much better to obtain the joint opening by addition and then to convert to resistance by inversion.

Mr. Penman rightly states that "the effect of natural ventilation is variable, and, in addition, its influence will not be the same when acting alone as when simply aiding the fan, which is the chief ventilating agent." He does not, however, show what is the exact influence of this important factor, to do which presents no great difficulty.

For any extensive mine the temperature of the air in the upcast shaft will not depend upon the volume of air circulated, for the natural heat of the strata will be quite able to maintain a uniform temperature in a greatly increased volume of air per minute. Thus the addition to the ventilating pressure due to natural ventilation will be constant, despite any possible increase in quantity. Hence all we have to do in order to allow for the influence of this factor is to superpose this constant pressure upon all other pressures due to ventilators.

Writing h_n for the constant pressure due to natural causes, we may modify the formula given by Mr. Penman on page 43 for the case of two fans in series, so as to give the volume due to natural ventilation and the two fans in series, thus :—

$$Q = \sqrt{\frac{h_1 + h_2 + h_n}{R + r_1 + r_2}}.$$

In a similar manner the formula given on page 46 for ventilators in parallel, in order to give the result of the series-parallel effect of natural ventilation in series with two parallel fans, may be modified thus :—

$$Q = \sqrt{\frac{h + h_n}{R + r_1}}.$$

Mr. Penman gives an expression for what he calls the "aero-dynamic efficiency-ratio" as being numerically equal to the air-resistance of the mine divided by the total air-resistance of the ventilating system. This, also, is a familiar ratio, and was expressed by Murgue in terms of the equivalent orifice of the mine and of the orifice of passage of the fan as being equal to $o^2 \div (o^2 + a^2)$.

Where o = orifice of passage of the fan, and
a = equivalent orifice of the mine.

Then writing $o^2 \propto \frac{1}{r}$ and $a^2 \propto \frac{1}{R}$,

this becomes $\frac{\frac{1}{r}}{\frac{1}{r} + \frac{1}{R}}$, or $\frac{\frac{1}{r}}{\frac{R+r}{Rr}}$, or $\frac{R}{R+r}$,

which is the relation given by Mr. Penman.

In applying this ratio to two fans in parallel, we must be careful to observe that there will be an increase of aero-dynamic efficiency-ratio which may be paid for very dearly in the extra power absorbed in running two fans instead of one. I should be surprised if the extra power so absorbed would not be found in practically every case to exceed any advantage gained in aero-dynamic efficiency-ratio.

Mr. Penman states that "it would not be easy to say, even approximately, what is likely to be the relation between the aero-dynamic ratio and the efficiency of the whole plant." Why should this be? It is surely only a matter of careful analysis, and is not such a ratio exactly what the practical man requires to know?

Before proceeding to state the results of the experiments at Wellesley Colliery, Mr. Penman remarks that "It should be noted that at present both fans are working at only about half their rated capacity. As the colliery develops—the mine is comparatively new—the quantity of air circulated will in all probability greatly increase." Both fans are stated to have a rated capacity of 200,000 cubic feet per minute at a water-gauge of 4 inches. It is clear from the tests that the fans are giving over 4 inches of water-gauge when running under normal conditions now, and it is, therefore, clear that an increased volume can be obtained only by increasing the equivalent orifice of the mine. This can result only from the opening-out of airways in parallel to those already existing.

If these fans have been designed so as to have an internal resistance of about 9 per cent. when passing 200,000 cubic feet per minute at 4 inches of water-gauge, the ratio $a \div o$ will be about 0·3. The value of a, the equivalent orifice of the mine, will be equal to $\frac{0{\cdot}39 + 200}{\sqrt{4}}$, or 39 square feet, and the value of o will thus be about 130 square feet. The equivalent orifice of the mine is now about 21·6 square feet. In these circumstances there can be no increase of mechanical efficiency in running these fans in parallel.

I am of opinion that the increase in mechanical efficiency due to the running of two fans in parallel is very problematic in any case. The total loss of a fan results from (*a*) loss of some of the initial velocity of the air entering the fan due to faulty rectangular deflections, (*b*) loss due to eddy-currents at the fan periphery, (*c*) loss due to friction of the air against the vanes and casing of the fan, and (*d*) loss due to kinetic energy in the air at the mouth of the evasèe.

In a properly-designed fan losses (*a*) and (*b*) will be reduced to very small dimensions. The losses (*c*) and (*d*) will be proportional to the square of the volume passed. The loss under (*d*) can be reduced by building a suitable evasèe chimney. If the outlet of the evasèe be made four times the cut-off area of the fan, the velocity will be reduced to one-fourth and the energy remaining in the air to one-sixteenth of what it was on entering the evasèe. As only 50 per cent. at most of the work done by the fan on the air can exist as kinetic energy at the point of cut-off, the kinetic energy carried away in the air would, in these circumstances, not exceed one-thirty-second, or about 3·3 per cent. With an evasèe outlet three times the cut-off area, the energy carried away would be only one-eighteenth, or about 5·5 per cent.

The total internal losses of a well-designed fan should not exceed from 10 to 15 per cent., and taking the losses to be proportional to the square of the velocity, if the velocity be halved by putting two similar fans in parallel to discharge the same total volume of air, the losses would be reduced to from $2\frac{1}{2}$ or $3\frac{3}{4}$ per cent., representing a saving of only $7\frac{1}{2}$ to $11\frac{1}{4}$ per cent. Against this we have to offset the running losses of *two* motors and *two* fan-shafts instead of *one*, and he would be a very sanguine man indeed who would expect in these circumstances to effect an overall increased *mechanical* efficiency.

The case of the overall efficiency of two fans in series is different, for in this case all the kinetic energy in the air discharged from the fan

nearest the mine is retained in the circuit, and is therefore not necessarily lost. Even although this fan is smaller than the fan discharging into the atmosphere, a fairly good overall efficiency may be obtained on this account. I have observed recently a case where a Sirocco fan working under these conditions had an overall fan-motor mechanical efficiency of 70 per cent.

In Part III. (conclusion 6) Mr. Penman states that "the increase of quantity obtained by running two similar fans in series at the same speed . . . . would in most cases be approximately equal to 35 per cent." He does not give experimental data in support of this statement, but, assuming its truth, it means that an increase from 100 to 135 would be obtained as compared with an increase from 100 to 141 if the second fan were to give 100 per cent. of increased effective water-gauge. This would show that fans in series can be quite profitably employed.

It is interesting to note that a problem similar to that of running fans in parallel is encountered in the parallel running of turbine pumps. Recently it was desired to secure an increased vacuum in the condenser at a large power-station, and an attempt was made to increase the water-circulation by putting in two exactly similar turbine pumps, driven by exactly similar three-phase induction-motors. Each pump had its own suction and delivery-pipe, the two delivery-pipes joining near the condenser. On running, the motors were found to *divide* the load between them equally, but practically no increase of water-circulation resulted.

An improvement, analogous to the application of the evasèe to a fan, has been suggested, in the form of an expanding outlet. Where sufficient difference of level exists between the condenser and the cooling-pond in such a case, an application of the siphon by allowing the water to siphon from the discharge outlet can frequently give an increase of effective head.

In conclusion, I would again congratulate Mr. Penman on the production of a very useful paper, which shows evidence of the very careful performance of the experimental part, and an equally clear comprehension of the true meaning of the results obtained.

The Chairman (Mr. Sam Mavor): It is unfortunate that when papers giving details of the results of measurements of efficiencies of fans, pumps, etc., are presented, they are all subject to the defect that the tests are taken according to the individual ideas of the men who read the papers. The tests are carried out by different methods, and therefore the results are not comparable, so that one of the greatest benefits to be derived from such tests is sacrificed and the value of the papers, and of the work undertaken in observing and recording data is very much discounted. It seems to me that there is an undoubted need for standardization of methods of testing. The whole question ought to be considered by a Committee of competent authorities, who should lay down a suggested standard of procedure for carrying out such tests and draw up tabular forms for the records. If such a course were followed, then we would have the very great advantage of being able readily to compare the results of one test with another—an advantage which, at present, we do not enjoy. Moreover, the existence of a specification of method and of a tabular form for recording data would induce many who have opportunity to make tests, but who for lack of guidance hesitate to take the initiative.

The further discussion of the paper was adjourned.

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

ANNUAL GENERAL MEETING,

HELD IN THE MAPPIN HALL OF THE UNIVERSITY OF SHEFFIELD, AUGUST 25TH, 1921.

MR. J. H. W. LAVERICK, RETIRING-PRESIDENT, IN THE CHAIR.

THE LATE MR. G. BLAKE WALKER.

The PRESIDENT: Since the last meeting of this Institute we have lost our old friend Mr. G. Blake Walker. Mr. C. C. Ellison has kindly prepared a memoir, which in his absence I will read.

MEMOIR OF THE LATE GEORGE BLAKE WALKER, J.P., M.ENG. (SHEFFIELD), M.INST.C.E.

BY C. C. ELLISON.

Mr. George Blake Walker was for many years one of the most prominent coal-owners of Yorkshire, and also one of the country's leading contributors to the progress of scientific mining.

He was connected for nearly forty years with the Wharncliffe Silkstone Collieries, where he introduced many modern appliances and methods of working. During the greater part of this period he was an outstanding member of this Institute, an important contributor to discussions, and always ready to test any new idea which could tend to the economy, safety, and efficiency of mining. His reputation as a mining engineer was almost world-wide. A man of genial kindness who was much esteemed by all who knew him, he will be missed as much for his personal qualities as for his conspicuous ability.

Mr. Blake Walker was born in 1854, and was the eldest son of Mr. Horace Walker. He married Miss Clarke, eldest daughter of Dr. Clarke, of Wentworth, in 1882, and lived at Tankersley Grange until 1919, when he retired from the Managing Directorship of the Wharncliffe Silkstone Collieries. He had been in failing health for some years, and died at Malvern on June 3rd, 1921, at the age of 67. He is survived by Mrs. Walker, two sons, and one daughter.

Mr. Blake Walker was educated at a private school near London. From there he went to Germany to study engineering, and he became greatly impressed with many of the German methods of working.

On returning from Germany in 1871, he was articled to Mr. George May, then Manager of the North Hetton Collieries, one of the largest colliery concerns in the County of Durham. On the completion of his apprenticeship, he returned to the Wharncliffe Silkstone Collieries, and was appointed Under-manager.

He devoted his attention specially to the introduction of coal-cutting machinery and the remodelling of underground workings, the condition

of which left much to be desired. At that time the ventilation of the colliery was produced by furnaces; these were done away with, and a fan was substituted.

Mr. Blake Walker was elected a Director of the company in 1885 and Chairman in 1888. Many innovations were introduced during the time he had charge of the collieries. The coal-washers of the "Lührig" system, which were erected in 1892, were the first of the large coal-washers erected in Yorkshire.

In 1897 the erection of a battery of bye-product coke-ovens was commenced in conjunction with the Simon-Carvès Company, and this was also a new departure in South Yorkshire. Further development included the utilization of the surplus gas from the bye-product ovens in gas-engines. The introduction of electricity enabled the pumping plant to be remodelled and simplified, and the same power to be used for haulage and coal-cutting.

When visiting some Austrian collieries in 1895, he was much impressed with the artificial breathing-apparatus used there for rescue and exploration work, and took up with enthusiasm their introduction into this country, in connexion with which he founded the Mining Engineering Company to import and manufacture them. This appliance is known as the "Meco" rescue-apparatus. The first joint rescue-station was erected at Tankersley before the provision of these stations was made compulsory by law. He also advocated the provision of miners' baths, in which proposal, however, not much progress has been made.

Mr. Blake Walker has advised in mining work in Australia and Canada. He visited Australia in 1890, and sent out a number of men from Birdwell and Hoyland Common, some of whom are still out there. He was also consulted by the Dominion Coal Company of Canada on the working of their under-sea coal.

In 1909 Mr. Walker undertook a report on a coalfield in the Rocky Mountains of Canada, a work which involved extreme hardships. On one occasion he was overtaken by a terrible blizzard while in a very inaccessible place, and later narrowly escaped being drowned. As a result, he sustained a severe shock to his system, which seriously impaired his health.

In 1881-1882 he was the first Lecturer in Mining at Firth College, Sheffield, before the foundation of the Mining Department and its full-time staff in 1901. He was Chairman of the Coal Mining Committee of Firth College, of University College, and of the University of Sheffield from that time until his death, and during the whole of that period took an active interest in the foundation and development of the department. His literary interests formed a link with other departments of the University other than mining. He was a member of the University Council of the Applied Science Committee, and of the Faculty of Engineering, and in 1918 received the Honorary Degree of M.Eng. in recognition of his long and valuable services to the University and its predecessors.

Mr. Blake Walker took a great interest in the Midland Institute of Mining, Civil, and Mechanical Engineers, of which he was President during 1896-1898, when he devoted his Presidential Address to the subject of the education of mining engineers, a theme which always had an absorbing interest for him.

In 1909 he succeeded the late Prof. L. T. O'Shea as Secretary and Treasurer of the Institute. Mr. Blake Walker was a member of Council of The Institution of Mining Engineers from its foundation in 1889, and

for many years was a member of the Finance and Publications Committee. He was one of the Institution representatives on two conferences called by the Imperial Mineral Resources Bureau. He was elected President of the Institution in 1918, but was forced to resign after the conclusion of his first year of office. During that time, however, he devoted much of his spare time to the furtherance of the interests of both this Institute and of the Institution.

In 1919 Mr. Blake Walker was awarded by the Midland Institute the "Peake Medal" for the conspicuous services that he had rendered to the Society.

The following are the papers written by Mr. Walker and published in the *Transactions* of The Institution of Mining Engineers :—

"Coal-getting by Machinery," vol. i., page 123.
"On the Parker and Weston Pump for Colliery Purposes," vol. ii., page 11.
"Notes on the Coal-fields of New South Wales," vol. ii., page 268.
"The Lührig System of Coal-washing," vol. vii., page 392.
"The Roth Method of Firing Shots," vol. x., page 95.
"The Education of Mining Engineers" (Presidential Address to the Midland Institute), vol. xii., page 132.
*"Recent Progress in the Recovery of Bye-products from Coke-ovens," vol. xiii., page 302.
"The Rhenish-Westphalian Coal-syndicate," vol. xvi., page 401.
*"The Utilization of Surplus-gases from Bye-product Coke-ovens," vol. xxix., page 187.
"On the Practical Use and Value of Colliery Rescue-apparatus, and the Organization of Rescue-corps," vol. xxxvi., pags 536.
"The Generation and Use of Compressed Air for Mining," vol. xliv., page 629.
"Making a Shaft Upwards," vol. lii., page 227.
"The Areas and Deposition of the Coalfields of Western Europe," vol. liv., page 77.
"Presidential Address" to The Institution of Mining Engineers, vol. lvi., page 211.

In 1896 Mr. Blake Walker was elected a member of The Institution of Civil Engineers, and contributed two papers, the first on "Bye-product Coke-ovens" (1899-1900, Vol. CXLII., page 308), and the second on "Recent Developments in Bye-product Coking" (1917-1918, Vol. CCV., page 104). Telford Premiums were awarded to Mr. Walker for both these papers.

As President of the Sheffield Society of Engineers and Metallurgists in 1920, he dealt with the "Waste of Fuel" question in his Presidential Address.

He was a Justice of the Peace for the West Riding of Yorkshire, and also a Director of the Yorkshire Engine Company, the North Central Wagon Company, and the Hull & Barnsley Railway Company.

He was a great lover of music, several of his compositions, amongst which may be mentioned a "Rustic Wedding" and "Ariadne in Naves," being very popular.

A portrait of Mr. Blake Walker appears as a frontispiece to Volume LVI. of the *Transactions*.

The PRESIDENT (Mr. J. H. W. Laverick): I do not feel that I can add anything to what has been written by Mr. Ellison, to whom we are indebted for preparing so full and complete a memoir of our old friend

* In collaboration with the late Prof. L. T. O'Shea.

and colleague. My earliest recollection of Mr. Blake Walker goes back to the early eighties, when I was a member of the British Society of Mining Students. Mr. Walker was a very active member of that little society, and took a great interest in its work. It only remains for me to ask the members to agree to send to Mrs. Blake Walker and the rest of the family a letter, expressing our very sincere condolences in the great loss that they have sustained.

The resolution was carried, all standing.

ABSTRACT OF ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

At the commencement of the year there were 498 members on the register; 68 new members have been elected, 12 members have died, 9 members have resigned, and the names of 19 members have been erased from the register for non-payment of their subscriptions, making a total present membership of 526.

The subscriptions of 456 members are fully paid, as against 429 for last year; the subscriptions of 51 members are in arrears, and 29 are only part paid, owing to the increased rate, which came into force on July 1st, 1920. The value of arrears of subscriptions is estimated at £226 11s., as against £200 11s. for the previous year. The total balance at the bank at the commencement of the financial year was £350 12s. 8d., and for the year just ended £707 19s. 4d.

The Council regrets to report the deaths of the following twelve members:—Col. T. W. H. Mitchell (President, 1904-1906; Secretary, 1890-1904), G. Blake Walker (President, 1896-1898; Secretary, 1909-1918), W. Hutchinson, C. E. Jeffcock, W. G. Greenwood, R. Nadin, T. Nodin, R. Richardson, G. A. Roberts, Thomas Gill, W. H. Brealey, and S. Crawshaw.

Six meetings were held during the year, at which six papers were read. The attendance at the meetings has been an improvement over that of the past few years, the average for this year being forty. The Council is of the opinion, however, that a much larger number of members might possibly be able to be present at the meetings, and urges them to do so in order to encourage the authors of papers by taking part in the discussions.

A large number of additions have been made to the Library during the past year, and members are invited to take advantage of the valuable facilities for reference which the Library offers. Those who do so by correspondence are asked to provide the Librarian with precise information as regards their wants.

The Council will be pleased to receive suggestions as to possible authors of papers, and subjects upon which papers are particularly desirable.

The Council hopes that all members will assist during the forthcoming year in nominating suitable gentlemen as members. At the present time there are still a number of mining engineers in Yorkshire who are not members of the Institute, and there are also a considerable number of mining students who should become members of the Student or of the Associate class.

The Midland Institute of Mining, Civil, and Mechanical Engineers: Abstract of Income-and-Expenditure Account for the Year 1920-1921.

Expenditure.	£ s. d.	£ s. d.
To The Institution of Mining Engineers: Calls on members	687 7 8	
,, Printing, stationery, binding, Library account, etc.	223 7 6	
,, Rent, insurance, telephone, hire of rooms, and cleaning	9 7 1	
,, Secretary's and Assistant Treasurer's and Librarian's salaries and expenses, and reporting	188 7 5	
,, Incidentals, bank charges, and income-tax	64 17 8	
,, Depreciation of furniture, publications, etc.	88 10 5	
,, Stamps and telegrams	40 14 11	
	£1,302 12 8	
,, Excess of income over expenditure ...	341 10 9	
	£1,644 3 5	

Income.	£ s. d.	£ s. d.
By Subscriptions—		
Current	1,427 14 6	
Arrears	51 9 0	
Paid in advance previous year ...	9 9 0	
		1,488 12 6
,, Dividends, bank interest, and income-tax refunded		155 10 11
		£1,644 3 5

Abstract of Balance-sheet for the year 1920-1921.

Liabilities.	£ s. d.	£ s. d.
Subscriptions paid in advance		29 17 0
Provision for outstanding liabilities ...		100 0 0
Capital account—		
As at May 31st, 1920	2,276 17 11	
Add Excess of income over expenditure	341 10 9	
		2,618 8 8
		£2,748 5 8

Assets.	£ s. d.
Investments at cost	1,749 19 2
(Actual value of above at June 30th, 1921, £1,452 0s. 6d.)	
Office furniture (*less* depreciation)	161 2 3
Publications (*less* depreciation)	129 4 11
Cash at bank	707 19 4
	£2,748 5 8

ELECTION OF MEMBERS.

MEMBERS—

Mr. RICHARD EDGAR BARKER, Colliery Under-manager, Woodland View, Purston, Featherstone, Pontefract.

Mr. FRED BUCKROYD, Colliery Manager, Kendal Green, Worsborough Bridge, Barnsley.

Mr. GEORGE R. COWLEY, Colliery Manager, Barrow Collieries, Barnsley.

Mr. KENNETH GORDON LAZENBY, Chief Surveyor and Assistant General Manager, Rokeby, Snydale, Pontefract.

Mr. RUDOLH LESSING, Ph.D., Consulting Chemist, 317, High Holborn, London, W.C. 1.

Mr. MICHAEL CLEEVE MARTYN, D.S.O., M.C., Colliery Manager, East Cottage, Wath-on-Dearne.

Mr. FREDERICK CHARLES SWALLOW, Managing Director, Tankersley Grange, Barnsley.

Mr. THOMAS LOMAS, Colliery Manager, Manor House, Darton, Barnsley.

ASSOCIATE MEMBERS—

Mr. DONALD HENRY CURRER BRIGGS, M.A. (Oxon), Company Director and Engineer, Hazel House, Methley, Leeds.

Mr. JOHN MACHENT, Colliery Under-manager, Whitwell, Mansfield.

Mr. HAROLD EDMUND PEARSALL, Mechanical Engineer, Pontefract Road, Cudworth, Barnsley.

ASSOCIATES—

Mr. GEORGE EDWARD BANHAM, Mining Student and Overman, Parkhead, Worsborough, Barnsley.

Mr. JOSEPH ELLSE, Mining Student and Deputy, Bakestone Moor, Whitwell, Mansfield.

Mr. ARNOLD PEACE, Mining Student and Colliery Worker, Whitley Tower, Dewsbury.

Mr. G. E. STEWART, Mining Student, 190, Whitham Road, Sheffield.

TRANSFERS FROM ASSOCIATE MEMBER TO MEMBER—

Mr. J. H. H. LAWSON-WALTON, Colliery Manager, Grange Colliery, Rotherham.

Mr. H. M. SWANSON, Chief Surveyor, Felkirk, Barnsley.

TRANSFERS FROM ASSOCIATE TO MEMBER—

Mr. WILLIAM KIRK, Colliery Manager, South Kirkby Colliery, Wakefield.

Mr. ARTHUR SAXON, General Manager, Tafo, Accra, Gold Coast Colony.

TRANSFERS FROM STUDENT TO ASSOCIATE MEMBER—

Mr. HAROLD JAMES ATKINSON, Colliery Under-manager, 9, Hilderthorpe Terrace, Garforth, Leeds.

Mr. GORDON GRAINGER, Working Pupil and Mining Student, 81, Industry Road, Sheffield.

TRANSFER FROM STUDENT TO ASSOCIATE—

Mr. GEORGE COOKSEY, Assistant Surveyor and Mining Student, 216, Midland Road, Royston, Barnsley.

THE FRICTION COEFFICIENT OF MINERALS.

By STANLEY NETTLETON.

In the preparation of minerals for the market or for metallurgical treatment it is generally necessary at some stage of the process for a sliding movement to take place on a hard surface of metal or other material. This sliding may take place in screening and in simple transit from one part of the plant to another, and these sliding effects may be utilized in order to separate one class of mineral from its natural associates of lower value.

The inclination necessary to cause material to move upon a sloping surface is governed by a number of factors which have received attention from manufacturers of mining appliances, but the question of angle of slope appears to be generally solved by empirical methods.

It has been found by experience that small material—say, of $\frac{1}{2}$-inch diameter—requires greater inclination to cause movement than pieces, say, 1 or 2 inches in diameter, and that unscreened mineral which consists of fragments of all sizes down to particles of dust does not move so freely down a sloping surface as mineral which has been classified into grades of approximately equal sizes.

The presence of moisture usually tends to hold up unscreened mineral on an inclined surface, but its effect is modified in the case of closely-sized material such as " nut " coal ranging from 1 inch to $1\frac{1}{2}$ inches in diameter.

As crushing is a prominent feature in ore-treatment, reduction in size of mineral is rarely disadvantageous, and for this reason chutes and screens at metalliferous mines are generally placed at inclinations much in excess of that necessary for free movement in order to avoid the possibility of holding up any of the mineral.

Data on the slope necessary to overcome the coefficient of friction of minerals appear to be very meagre, but the subject has been referred to by several authors. Prof. Henry Louis states that :—

". . . it is necessary to distinguish between the angle at which a mineral just commences to slide (a) and that at which it continues to slide at a uniform velocity after it has started from rest (Φ)." *

He gives the result of determination upon moderately large lumps of various minerals sliding upon a smooth steel plate as follows :—

	a Commences to slide. Degrees.	Φ Continues to slide after it has started from rest. Degrees.
Coal	30	26
Quartz	$25\frac{1}{2}$	20
Magnetite	28	$18\frac{3}{4}$
Limestone	$31\frac{1}{2}$	21
Galena	24	15
Zinc blende	25	$15\frac{3}{4}$
Fibrous red hæmatite...	$25\frac{1}{4}$	$16\frac{1}{2}$
Calcspar	27	20

* *The Dressing of Minerals*, 1909, page 13.

From this table it may be assumed that the slope necessary to initiate movement may be anything from 24 to 31½ degrees, or 4 to 10½ degrees more than that which will maintain motion after a mineral has commenced to slide on an inclined plane.

Materials such as quartz, coal, and limestone vary so much that some information is desirable on the physical character of the specimen tested—limestones may be soft and friable or hard and semi-crystalline. The term "coal" includes materials varying in specific gravity from 1·15 to 1·45 and of widely different physical character. Gas-coal frequently breaks into fragments of more or less cubical form; cannel coal has often a semi-conchoidal fracture; anthracite breaks very irregularly; and lamellar structure is not unknown in lignitic coal.

Form, size, specific gravity and hardness may each have an influence on the angle of slope at which a piece of mineral will commence to move or continue to move when placed on a smooth surface.

Breakage is a matter of importance in the handling of coal, and the friction coefficient may be a factor used in the dry separation of coal from shale. In order to determine the principles underlying the behaviour of coal and the rocks with which it is associated in the mine, a large number of experiments were made on the following lines:—

Samples of materials were broken and separated into classes of approximately similar sizes by screening; wire screens with square meshes of $\frac{3}{16}$, $\frac{3}{8}$, and $\frac{5}{8}$ inch were used to make three classes, and it should be noted that closeness of sizing is governed to a considerable extent by the form which each mineral assumes when broken. Shales have a tendency to break into pieces in which the length and breadth are disproportionate to the thickness, whilst pieces of coal and anthracite usually assume a more or less cubical or spherical form.

For this reason, on shaking coal and shale over a ½-inch mesh, the shale passing through the screen will contain more pieces over ½ inch in length than is the case with coal-sizing.

A small quantity of sized material was placed gently upon an inclined sheet of plate-glass, which was tapped three times in each experiment. There was then noted the proportion of material which slid off the inclined plane. Results were apt to be rather irregular, particularly near the points at which the material did not move at all, or the whole of it slipped off the glass. The results here given are averages of not less than five tests for each point of sliding. The following is an example of a test. A large number of pieces of Yorkshire bituminous coal were placed on a sheet of glass 36 inches in length at an angle of 22 degrees. In placing material on the inclined surface each particle was put in contact with the medium over which it slided, so that carrying and packing effects were eliminated as far as possible. The size of the coal was through $\frac{5}{8}$- and over $\frac{3}{8}$-inch mesh, and the percentages of pieces of coal which moved to the bottom of the plate on tapping in nine experiments in these tests were 75, 85, 75, 70, 65, 80, 70, 75, 70; giving an average of 74 per cent.

About 700 experiments were carried out on a considerable number of pieces of mineral. Large numbers of pieces were used in each of these experiments and averages were taken, in preference to a small number of carefully-selected specimens being used which would have given more concordant results. Owing to the irregular nature of the materials dealt with in practice, it was believed that the former method would give the more useful results although these results would be of a more relative character. The results of these

experiments are summarized in the curves shown in Figs. 1 to 6. It will be seen from these that the sliding of minerals over plane surfaces appears to be subject to the following laws :—

(1) Large pieces of coal have a less coefficient of friction than smaller

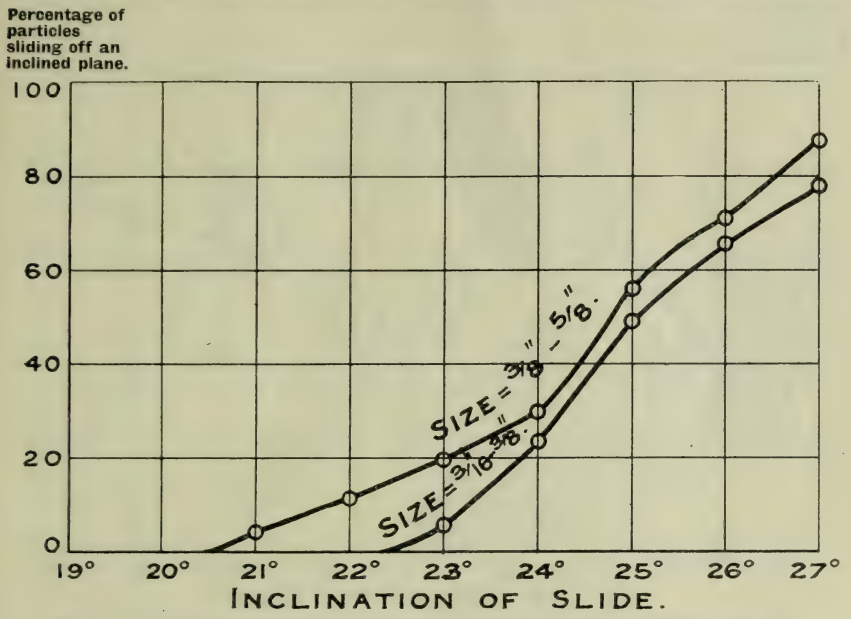


FIG. 1.—DIAGRAM SHOWING THE EFFECT OF SIZE ON THE COEFFICIENT OF FRICTION. COAL FROM BEESTON SEAM, WEST YORKSHIRE.

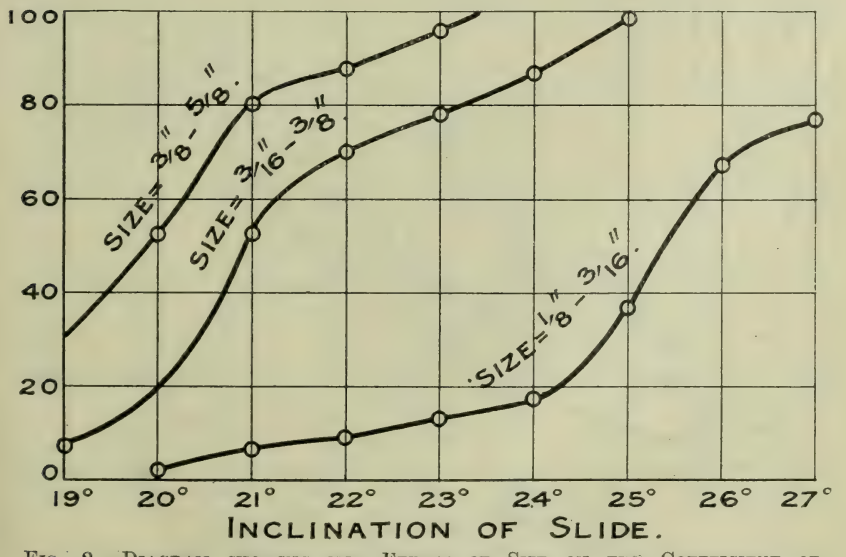


FIG. 2.—DIAGRAM SHOWING THE EFFECT OF SIZE ON THE COEFFICIENT OF FRICTION. BLUE BIND, A TYPICAL COAL-MEASURE SHALE, FROM YORKSHIRE.

ones—that is, when set in motion they will continue to slide over a plane which is at a lower inclination (Figs. 1 and 2).

(2) Material which is freshly broken does not slide so readily over a smooth surface as material which has been standing some time before it

is dealt with (Figs. 3 and 4); apart from the well-known fact that different minerals have different coefficients of friction (Figs. 5 and 6).

The force in these experiments tending to move a particle may be taken as the component of the weight parallel to the plate—that is, the

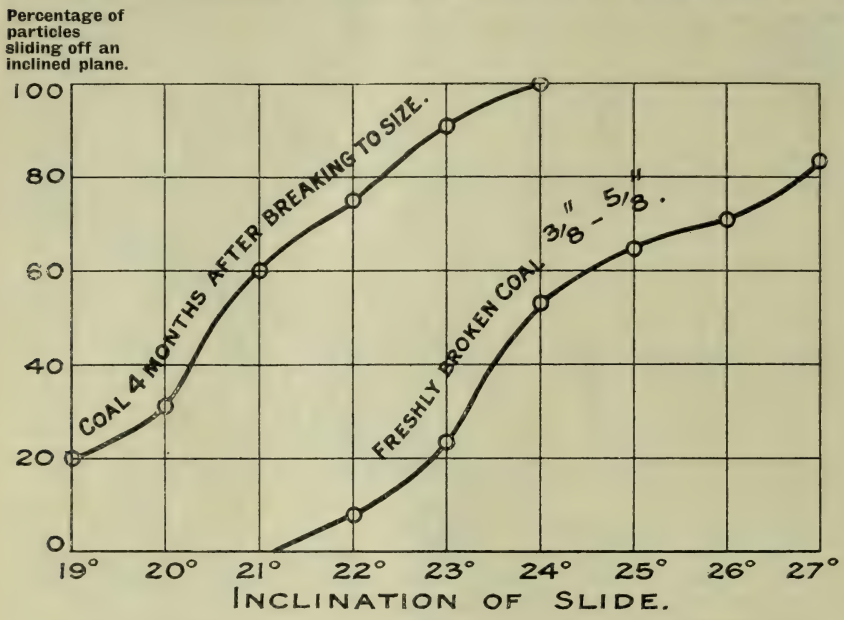


Fig. 3.—Diagram showing the Effect of Time on the Coefficient of Friction. Coal from Silkstone Seam, West Yorkshire.

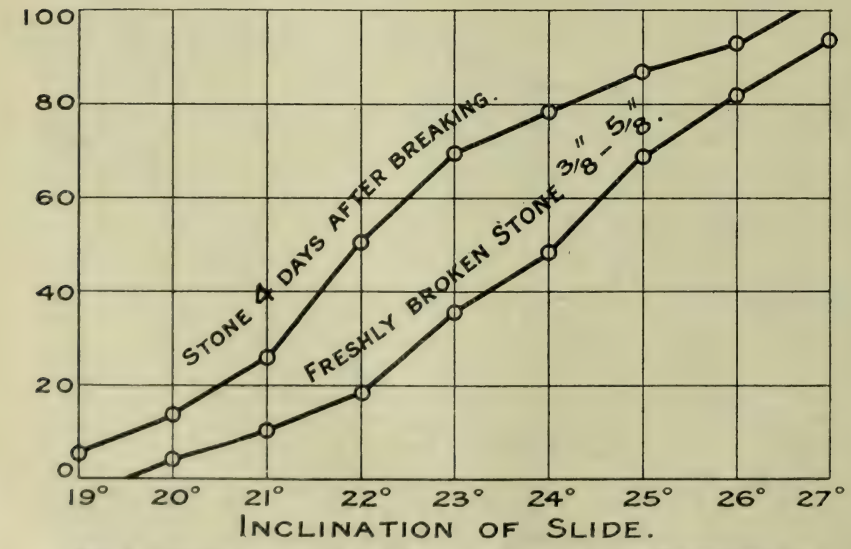


Fig. 4.—Diagram showing the Effect of Time on the Coefficient of Friction. Seat-earth or Fireclay from Coal-measures, West Yorkshire.

weight × cosine of angle of inclination of plate; and the purpose of the experiments was to obtain information on *relative* friction coefficients rather than absolute determinations.

The principles deduced in this paper have been found equally

applicable to the sliding of minerals on steel surfaces. I hope to describe in a subsequent paper how, by the application of these laws of dynamic friction, coal is being separated from shale and other undesirable associates by mechanical means.

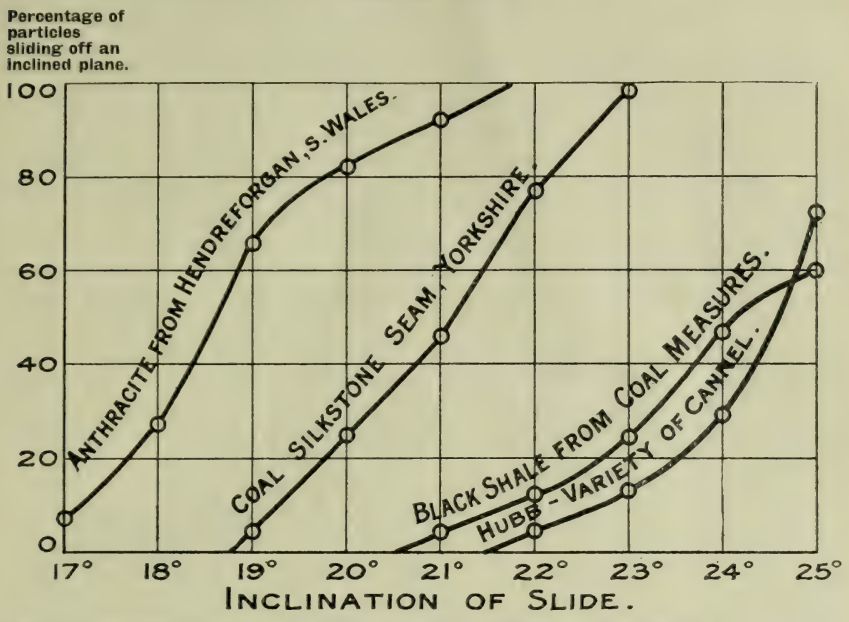


FIG. 5.—DIAGRAM SHOWING THE RELATIVE COEFFICIENT OF FRICTION OF COAL AND ASSOCIATED ROCKS. MATERIAL THROUGH $\frac{3}{8}$- AND OVER $\frac{3}{16}$-INCH SCREEN.

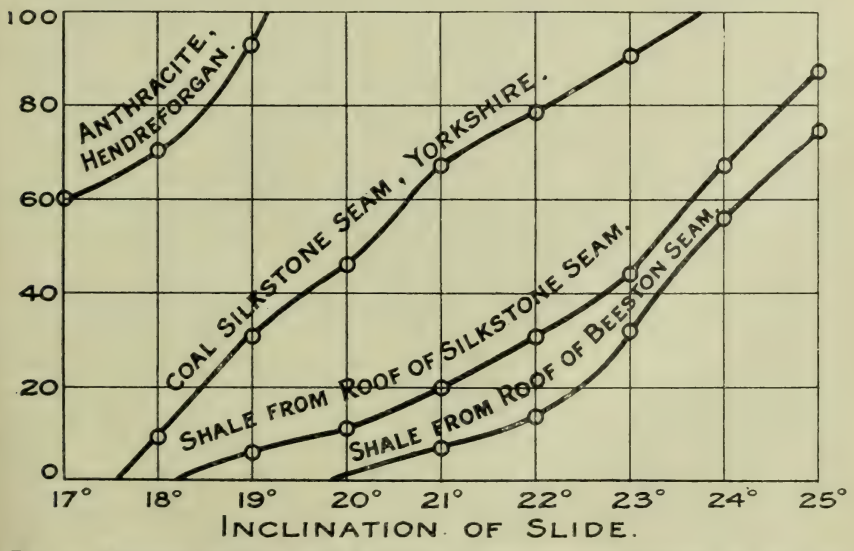


FIG. 6.—DIAGRAM SHOWING THE RELATIVE COEFFICIENT OF FRICTION OF COAL AND ASSOCIATED ROCKS. MATERIAL THROUGH $\frac{3}{8}$- AND OVER $\frac{3}{8}$-INCH SCREEN.

The experiments on which these observations are recorded were carried out in the Mining Department of the Royal School of Mines, to which and to Prof. Truscott I am indebted for facilities in carrying out the research.

Mr. Stanley Nettleton (London): I wish to point out that the curves are fairly regular, and are governed by some definite laws. It was suggested to me that I should deal with the theoretical side in the present paper, and with the practical work in a subsequent paper when matters are more fully developed, but the President has asked me what is the practical application of the work. The practical point at which I am aiming is the separation of coal from shale by mechanical means. If we can have a machine which will deal with the friction effect in such a manner that shale can be picked out of coal, something of value to the mining community will have been obtained. It should be noted that these friction effects are relative, and not absolute. Supposing that on placing a quantity of coal and shale upon a plate inclined at an angle of 19 degrees, and that on vibrating the plate there slides off 95 per cent. of the coal and 5 per cent. of the shale: then if the dirt forms 10 per cent. of the whole of the material and 95 per cent. of this remains on the plate, the effect will be a reduction in the amount of dirt from 10 to 0·5 per cent. in material sliding off, with loss of the 5 per cent. of coal which remains on the plate. By increasing the inclination of the plate, the frictional effects are modified, so that no coal will remain on the plate, but a larger amount of shale will move off and the cleaning efficiency will be reduced.

These results are obtained from the sliding effects of the material on a glass plate, but glass has the same frictional effects, although in a rather different degree, as steel. It would, however, be impracticable to have a long steel slide over which material has to be shot, owing to the cumbrous nature of such an arrangement. The friction could be increased by passing the material down a moving surface, such as a belt, so arranged that during the passage over 10 feet of space the belt would move forwards—say, 50 feet. By that effect 60 feet of friction on the belt would be obtained. The next point would be to devise some means of removing the material or of preventing colliding effects. I got over this difficulty by dividing the path of friction into two portions—one in a fixed straight line, and the other in a moving surface—which arrangement, for practical purposes, was most convenient in a rotating steel disc.

(Mr. Nettleton then exhibited a small experimental model, in which a steel disc 2 feet in diameter was rotated by a motor, and material was fed down a spout on to the disc. The coal went straight forward across the disc, while the shale turned off at an angle.)

Mr. Nettleton: When an arrangement such as this is fixed up on satisfactory engineering principles, it is possible to obtain an almost perfect separation of coal or anthracite from, say, associated shale. The theoretical principles evolved in the tables are borne out almost exactly by the rotating disc. If an anthracite, a blue bind, or pyrites, has a certain relation to another material, as shown by the curves, I get the same relation on the moving disc.

Mr. A. Blenkinsop (Dalton Main): Have any experiments been made with soft coal?

Mr. Nettleton: I have tried the machine on anthracite, gas-coal, and steam coals, and find that anthracite gives the best results, as in physical properties it is further removed from shales and dirts than the ordinary Silkstone or Barnsley coal. It is, however, possible to have a cut which will give a sufficient distance between a black shale and a coal so as to get separation. At first sight it might be said that a machine

such as I am exhibiting cannot deal with a large quantity of material. It could not in the experimental form, but by using the two sides of the disc the capacity of the machine is doubled, and if the shaft be vertical it would be possible to have a number of discs on the shaft, 6 or 8 inches apart, when dealing with nut-coal. It would then be possible to multiply the capacity of the machine twenty times.

The President (Mr. J. H. W. Laverick): An ounce of practice is worth a ton of theory, and if it had not been for the demonstration that we have witnessed I think that some of us would have been somewhat sceptical regarding the capabilities of the machine. The model which Mr. Nettleton has exhibited has been invaluable in this respect, and he has added greatly to our indebtedness by the trouble he has taken in order to demonstrate the practicability of his appliance. Whether this system will ever supercede coal washing remains, however, to be proved.

Mr. W. McD. Mackey (Leeds): The subject is one in which I have been for a long time interested. I read a paper before this Institute in 1904, in which I described a method of separating dust from coal.* The principle was that of a revolving belt set at an angle, the dust clinging, whilst the large pieces rolled down, and I had good results. I tried the same principle for separating coal and shale with some success. I also experimented on Low Moor shale (flat shale with cubical pieces of ironstone), and obtained a very good separation, but the expense was an obstacle, as it was necessary to handle 20 tons of material in order to recover a ton of ironstone, so that I did not go any further with the venture. I think Mr. Nettleton's principle is a much better one than my own, and I can see success for it.

The President: What would be the effect of the difference between a piece of pyrites and a piece of ordinary bind.

Mr. S. Nettleton: Pyrites, as found in coal, differs considerably in character. Sometimes pyrites is found in the form of balls, some of them as round as cricket balls. If they are spherical, they have a tendency to run down the shoot and bolt across the plate; but clean or flat pyrites gets a grip on the plate and is rejected as very bad dirt. The worse the dirt is—the higher percentage of ash it contains, and the nearer it is akin to fireclay—the further it is removed from the coal. I have found that by mixing together bituminous coal, cannel hubb, and fireclay, I can get the mixture to move off at three different points, and it is possible in a working machine to make three products. Material intermediate between coal and dirt, forming, say, 10 per cent. of the whole, might be put into a special division. If this 10 per cent. consisted of pieces which were part dirt and part coal, it could be put through a crusher and a small separator afterwards, or it might be passed on to a picking-belt so as to take out bits of coal that had been rejected as dirt. It is all a question of economies. It might pay to lose a small percentage of coal with the dirt in order to get the whole of the dirt removed. Clean broken pyrites is removed very effectively.

Mr. J. Brass (Houghton Main Colliery): What is the smallest coal with which Mr. Nettleton has experimented? In the Barnsley Bed there are Hards, Softs, and a clay-seam. The coal is supposed to be separated

* "Slack-washing: Preliminary Treatment for the Extraction of Fine Dust," *Trans. Inst. M. E.*, 1903-1904, vol. xxvii, page 55.

underground, but that is not always the case, and it comes to the pit-head very mixed, particularly in the case of small coal. How would the apparatus just shown deal with such stuff? Would it be possible to get the hard nuts and soft nuts quite clean from the dirt, or would there be some intermingling?

Mr. Nettleton: I have not made many experiments with smalls on the rotating disc, but I think that they could be dealt with by running them over smaller discs at a higher velocity. With regard to sorting out the different qualities of coal, it would probably result in the dirtiest coal, or the coal of one peculiar structure, going into one division and coal of another class into another.

The President: So that it might be possible to separate coals of different specific gravities?

Mr. Nettleton: With fine adjustment there is a tendency for coals of different characters to be separated. Anthracite can be separated from a Silkstone coal.

Mr. Blenkinsop: What is the widest stream of coal that has been used?

Mr. Nettleton: Four inches. It was required to have all the material in a single stream; it did not matter how fast the pieces of coal came behind each other, provided that they did not get opposite each other. If a piece of dirt on the right of the course has a tendency to pass over to the left, and there is a piece of coal in the way, something is lost.

Mr. Blenkinsop: That is what I thought might happen, owing to the fine coal being pushed over by the large pieces of dirt. If a large piece of dirt came in at the right of the shoot, it would tend to push over some small coal.

Mr. Nettleton: It is not a case of "pushing" over with the sizing; it is a case of friction varying with the size of the material.

Mr. Brass: In coal-washing the greatest trouble we have to face is the slurry, or very fine dust. Would it be possible for a machine like that exhibited to separate the coal and dirt?

Mr. Nettleton: I have not experimented with very fine dust.

Mr. S. J. Rayner (Canklow): What size of machine would be required to deal with 60 tons per hour? Is it the hardness or the specific gravity that is the determining factor in making the separation?

Mr. Nettleton: There are three factors to be considered. One is the specific gravity, which has a bearing on the velocity at which the material goes down the spout. Then there is the form of the material: a flat piece would not, of course, slide so quickly as a piece of other form, as it tends to get a better grip on the moving plate. There is also the coefficient of friction. I arranged for all these factors to pull in the same direction when designing a cleaning machine.

Mr. Rayner: You might have to deal with a piece of hard coal with another of coal at the bottom, which would have a kind of brake action.

Mr. Nettleton: I have taken pieces with different sides, and it has been somewhat problematical to know which way they would go. But the human element is also unreliable on a picking-belt.

Lt.-Col. H. Rhodes (Rotherham): From an examination of the results of the experimental machine, it would appear that the error is in the right direction. Very little coal seems to go away with the dirt—if there is a mistake, it is in the opposite way. It seems to me that if the machine could be devised on a practical scale, it might take the place of a number of boys engaged in picking coal. Certain people to this day do not like washed coal if they can get a fairly clean hand-picked coal; but with the human element it is impossible to remove all the dirt. This machine would, therefore, appear to have a future in that respect, where something better than we can expect from hand-picking is required, but not quite so good as we ought to get with a washer. If, however, the disc in the experimental machine is the largest that can be used, I am afraid that it would be an expensive matter to work the process on a practical scale.

Mr. Nettleton: The machine exhibited is only a model. The capacity can be increased twenty times, and I think that a machine of that size would serve as a fairly satisfactory working plant.

Mr. Rayner: Has Mr. Nettleton tried to separate material by making it leap across a gap, thus taking advantage of the velocities?

Mr. Nettleton: No; I do not think attempts of the kind have been successful, as a rule.

Mr. Rayner: The method has been tried in Glasgow for separating flood-water from normal water. The former goes down a shoot with sufficient velocity to leap over a gap, while the latter drops down below.

Mr. Brass: I think that such a system has been adopted in gold-mining. A stream of water carries the particles forward, and the specific gravity of the particles separate them into various chambers.

Mr. Nettleton: There is an American coal-cleaning arrangement which works upon the jumping-gap principle. The material passes down a long shoot in which there is a gap through which the dirt drops. The coal, owing to its moving at a greater velocity than the dirt, leaps the break and is carried forward on an extension of the shoot. The arrangement is very wasteful, owing to the large percentage of coal lost with the dirt. It can be used only where coal is mined or quarried at very low cost, where loss is not a serious matter compared with the production of a clean coal, and where there is ground available for cheaply dumping large quantities of refuse, as on the side of a hill near the mine.

DISCUSSION OF PROF. F. E. ARMSTRONG'S PAPER ON "MEMORANDUM NO. 1 OF THE MINERS' LAMPS COMMITTEE ON THE PASSAGE OF THE FLAME OF AN EXPLOSION THROUGH WIRE-GAUZE."*

Mr. Thomas Stubbs (Sheffield) wrote: I was much interested in this paper and the discussion thereon, also in the observations made by Lt.-Col. H. Rhodes and Mr. E. W. Thirkell in regard to outbursts of gas. The following are a few brief notes of several outbursts of large volumes of gas in the Parkgate Seam at Rotherham Main Colliery, and confirm

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 166.

the statement made by Col. Rhodes respecting outbursts of gas in that seam.

No. 1 *Outburst*, 1896.—This took place in the First West District in a bord 12 feet wide and about 5 feet high. A solid block of coal, 4 feet thick and the whole width of the bord and height of the seam, was separated from the face and removed a distance of 3 feet. A large feeder of gas was given off at the same time, and several lamps were extinguished.

The workings were soon cleared of gas, as the district was only a short distance from the downcast shaft.

No. 2 *Outburst*, 1897.—This took place in the Third West District in a bord 12 feet wide. About 10 a.m. a considerable amount of gas was given off, and twelve Thorneburry safety-lamps were extinguished. As the men were alarmed, they got out of the pit as quickly as possible, leaving a portion of their clothing in the working-faces.

By increasing the volume of air, the accumulation of gas was cleared away and was diluted at the point of issue.

No. 3 *Outburst*, 1900.—This took place in No. 40 ending, Norfolk Plane, was of a serious character, and extinguished thirty Thorneburry lamps. The men left the workings as quickly as they could, without lights and with only part of their clothing; three ponies were left in the face of the workings by themselves (the drivers having gone out with the men), and these were got out with some difficulty in the dark by the Under-manager, Charge Deputy, and one of the Corporals. The ponies had been amongst the gas for some time before being rescued, and both they and the officials who brought them out were very much affected by the impure air. Gas could be easily detected on the flame of the safety-lamp in the main return airway at a point about half-a-mile from the seat of issue, and within a short distance of the upcast-pit bottom.

After the workmen had been cleared out of the mine and no one left therein except the officials, the speed of the fan was increased, and after a few hours the workings and returns were cleared of gas.

No. 4 *Outburst*, 1901.—This took place in the same ending (No. 40), and occurred about 9 p.m. just as the men were finishing their shift. Most of the workmen had ceased work, and those who remained had their lamps extinguished. The Under-manager, on being informed, went down the pit at once. He first examined the return at the bottom of the upcast shaft, at a point approximately 1,000 yards from the place of issue, and got a gas-cap on his light of about $\frac{3}{4}$ inch.

The gas in the workings and returns was in this case very difficult to remove, and this was only effected by curtailing (temporarily), by means of brattice stoppings, the quantity of air going into other splits, thus causing an abnormal quantity of air to pass through the district affected before the accumulation of gas was cleared away and the pit got ready for work the following day.

Mr. Gerald T. Newbould (Earl Fitzwilliam's Collieries) wrote: Has the Miners' Lamps Committee had the opportunity of investigating any device other than a wire-gauze for preventing the passage of flame? Messrs. Ackroyd & Best, Limited, had at one time a large number of perforated sheet copper-gauze lamps in use in Scotland, with, I think, satisfactory results; but ordinary wire-gauze was substituted when the double-gauze rule came into force. There was also the "Best" lamp, which I believe did not have a wire-gauze; but perhaps the fact that this

lamp is not now on the market points to the superiority of ordinary wire-gauzes over anything yet invented. However, the performances of the new model " Best " lamp will be awaited with interest. I should also like to know whether the Committee has made experiments in the direction of using two gauzes of different mesh, or with more than two gauzes of large mesh.

Mr. J. S. Hayes (Sheffield): In addition to what has already been said about outbursts of gas, it might be interesting to know that when in New Zealand I was informed by my mining tutor of a certain outburst at the Metropolitan Colliery, Australia. Outbursts were fairly frequent there. The greatest of them killed two men engaged at the working-face, and also the pony and driver who were some 20 yards back. I understand that when the fan at this colliery is stopped for a few days, it is necessary to keep safety-lamps at night some distance round the upcast-shaft top, on account of the presence of gas on the surface.

Lt.-Col. H. Rhodes (Rotherham): At No. 2 Pit of the Durban Navigation Collieries, Natal, there are two shafts, each 18 feet in diameter and 560 feet deep; the management have just about driven round the shaft-pillar and have opened out seventeen working-places 14 feet wide. The fan was stopped at 12 o'clock noon on Saturday, January, 1920, in order to take off the fan belt. At 2.30 p.m., when this work was in progress, a man standing in the fan-house, outside the fan-drift, and close to the belt, lit a cigarette, when an explosion occurred. The tops of both shafts were blown off, and the whole place was completely wrecked. The quantity of air circulating at 12 o'clock, when the fan was stopped, was said to be 120,000 cubic feet per minute, in addition to which there would be a certain amount of natural ventilation, and yet so much gas was given off that in $2\frac{1}{2}$ hours there was enough in the fan-house to cause this violent explosion.

Prof. F. E. Armstrong (Sheffield University): The question of outbursts of gas did not strictly arise on the subject of the paper, which is on the effect of an internal explosion in the lamp. It was reserved for further researches to ascertain the effect of larger meshes of wire-gauze when there is continuous burning of firedamp within the lamp, and it is on these further researches that the question of outbursts arises. I do not think I can say anything at present for publication on these further researches.

In reply to Mr. Newbould, experiments have been made on the use of perforated plates in place of wire-gauze, and the results will be published shortly. The " Best " gauzeless lamp is certainly on the market, and depends—at any rate, in part—on the use of perforated plates instead of wire-gauze. It is an approved lamp, which has passed the necessary tests.

I do not think any experiments have been tried with two gauzes of different mesh. The general idea has been to find a safe single gauze, and possibly to add a second gauze as a protection in case the single gauze should be damaged. For the same reason, experiments have not been made with more than two gauzes, or with gauzes of different mesh. The primary object the Committee has had in view is to find a gauze that is safe as a single gauze when in perfect condition.

The discussion on the paper was closed.

The discussion of Mr. John L. Hodgson's paper on "Metering of Compressed Air," was closed.

ELECTION OF OFFICERS.

Lt.-Col. Harry Rhodes was unanimously elected President for the ensuing two years.

The RETIRING-PRESIDENT (Mr. J. H. W. Laverick): I am sure that Colonel Rhodes will carry on the traditions of the Presidency with very great credit to himself, and that the Institute will continue to grow and prosper during his period of office. His activities are not confined to this country, but have taken him abroad. He has visited three continents: he is interested in mines in South Africa, he has visited India in connexion with mining practice, and he also visited Central Asia. His experience is, therefore, wide and great. He is the son of a distinguished father, but, quite apart from that, he is thoroughly qualified on his own merits to fill the position to which he has been elected.

A hearty vote of thanks was accorded to Mr. Laverick for his work as President during the past two years, the resolution being carried unanimously.

Mr. J. H. W. LAVERICK: When I look through the list of papers that have been read during the past two years I am filled with pride. I have been most splendidly supported during my term of office by the readers of those papers, which were worthy additions to the *Transactions*. I can assure Colonel Rhodes, therefore, that he need not enter upon his Presidency with any fear or trepidation, as he will, I feel sure, receive similar support from the members, and further papers will be forthcoming. In conclusion, I can only express my sense of indebtedness to the Members of Council and the Secretary, who have also supported me splendidly, and to all those members who have attended the meetings, and thus made the average attendance during the past two years a very good one.

THE MINING INSTITUTE OF SCOTLAND.

GENERAL MEETING,

HELD AT THE HERIOT-WATT COLLEGE, EDINBURGH, OCTOBER 8TH, 1921.

MR. ROBERT McLAREN, M.P., PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were declared elected :—

MEMBERS—

Mr. GEOFFREY MERTON GALLICK, General Manager, Mining Department of Messrs. Mavor & Coulson, Limited, 47, Broad Street, Mile-End, Glasgow.

Mr. EI KATSUMATA, B.Sc., Mining Engineer, Mitsubishi Mining Company, Limited, Tokyo, Japan.

Mr. JOHN PENMAN, Colliery Manager, Roselea, Pencaitland, East Lothian.

Mr. JAMES ERNEST PHELPS, Assistant General Manager, Jealgora, Jamadoba P.O., District Manbhum, Bihar and Orissa, India.

Mr. THOMAS RIDDELL, Colliery Manager, Drumgrange, Fauldhouse, West Lothian.

ASSOCIATE MEMBERS—

Mr. WILLIAM INGLIS, Oversman, Council Crescent, Neilson Street, Bellshill, Lanarkshire.

Mr. NORMAN S. RUSSELL, Mining Engineer, Bayfield, Newmains, Lanarkshire.

STUDENTS—

Mr. ARTHUR ANDREW BEARD, Apprentice Civil and Mining Engineer, c/o Telfer, 88, Hyndland Street, Partick, Glasgow.

Mr. JOHN BLACKWOOD DRINNAN, B.Sc., 60, Dixon Avenue, Crosshill, Glasgow.

Mr. JOHN GLEN FINLAY, Mining Engineer, 4, Grantlea Terrace, Mount Vernon, Glasgow.

Mr. CAMPBELL RITCHIE, Mining Apprentice, "Sunnyside," Carfin Street, New Steventson, Holytown, Lanarkshire.

DEATH OF SIR WILLIAM GARFORTH, LL.D.

The PRESIDENT : We have to mourn the loss of Sir William Garforth, who has passed over to the great majority since the last meeting of the Institute. Because of the extraordinary amount of good work that the late Sir William Garforth did for the mining industry—the experiments he carried through in connexion with the coal-dust question, and his many other notable achievements on behalf of safety in mines in general—the country owes him a very great debt of gratitude. As you are all aware, it was he who introduced the "Weg" rescue-apparatus, and he always took a great interest in mine-rescue work. The mining engineers of Scotland and England to-day are much the poorer because of his removal by death. Meeting here as part of The Institution of

Mining Engineers, I think it would be fitting that we should express our sympathy with those who are left behind to mourn his loss. When I saw him last, he seemed, in the physical sense, to be going downhill very quickly, but he told me that so long as he was able to go about he would continue to carry on to the end. That was the spirit of the man, and looking back over his life I feel that it would be well for us if we would emulate his great work. I move that the condolence of the Institute be sent to the family of the late Sir William Garforth.

The resolution was carried by the members standing.

DEATH OF MR. ALEXANDER FAULDS.

The President: I feel it is only fitting to refer here to the passing of one of the prominent members of this Institute—a gentleman who was one of its original founders, namely, the late Mr. Alexander Faulds, who died recently in Vancouver. I am quite sure that all of us look back with pride to the work of Mr. Faulds, who pioneered the Mining Institute of Scotland, and made it the power of good that it has proved to be amongst the mining community. I propose that we give expression to our deep regret at the loss that we have sustained by his death.

The resolution was carried by the members standing.

DISCUSSION OF PROF. HENRY BRIGGS'S PAPER ON "PHYSICAL WORK AND THE HUMAN MACHINE."*

The President (Mr. Robert McLaren, M.P.): In view of what has occurred recently, bearing upon the physical work of the human machine, I think that it is probably fair to assume that some people can do more than they have hitherto been doing. We see in some of the coal areas that the output of coal has to be doubled, and I suppose that if the men cared they might even do more than that. It shows us how fallacious it is sometimes to put down a certain amount of work to a man when he is capable of doing far more. I think we must all agree that very much depends on the man himself. We have the case of some men offering to do more, because they are willing to work; but, again, there are others who are not willing to work. So long as human nature is as it is, I suppose we shall be confronted with that anomaly.

Prof. Henry Briggs (Edinburgh), in reply, wrote: Both Mr. James Cooper and Mr. Joseph Parker have indicated directions in which this type of experimental study may be extended. I fully agree with their remarks, and hope some day to ask their co-operation in enquiries of the kind they suggest. Mr. Parker's example of the results obtained in America for the operation of shovelling is a good one. Here we have a series of tests with one of the homeliest of tools which yielded astonishing results; yet these tests called for no special scientific training: they merely required that those conducting them should have patience, common sense, and a lack of prejudice. They suggest the need for similar tests being made underground, where restriction of space imposes conditions for muscular effort which differ from those at the surface; they also suggest the advisability of making a similar set of tests with the

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 26; and 1921-1922, vol. lxii., page 34.

pick—which is still the most important means of undercutting, even in Scotland, and overwhelmingly so in England and Wales. I believe that such trials—if their results were acted on—would mean an increase of hundreds of thousands of tons in the country's annual output. The fact that they would seek to determine how the largest output could be secured with the minimum expenditure of physical effort ought to commend them to both owners and men.

I also agree with Mr. Mavor that there are operations in mining—manual " drawing " is the glaring example—which should be cut down to a minimum, if only for the sake of those engaged in them. With mechanical methods of getting and transporting mineral developing at the rate they are now doing, and with the improvements in laying out the workings which those methods impose, it is becoming increasingly clear that it pays neither owners to employ men, nor men to be employed, in labour in which intelligence is of little or no account.

The discussion of the paper was closed.

DISCUSSION OF MR. WILLIAM McNAUGHT'S PAPER ON " THE ' BEAM ' ELECTRIC HEAD-LAMP."*

The PRESIDENT (Mr. Robert McLaren, M.P.): Mr. John George, of Cambuslang, is to show us this afternoon another electric head-lamp—the " Ceag." He is doing this with a view to giving us additional information, and proposes to tell us what he knows about the lamp.

Mr. JOHN GEORGE (Cambuslang): My first words on rising must be to wish the " Beam " lamp every possible success. The " Ceag " lamp has, as you see, an aluminium case, and fittings connected to it which render it perfectly dust-proof. The cell is a dry one—that is to say, a new absorbent is used. For many years now we have fitted our standard type of lamp with a jellac cell, and with great success. For this cell here we claim that it is non-spillable, and one of its virtues is that there is no corrosion whatever. With this head-lamp it is possible for the wearer to work any place in the pit, including the coal-face. The catch for the wearer's cap is exactly the same as in the case of the ordinary oil cap-lamp as used in Scotland and the United States.

Speaking of cap-lamps in general, I have had, along with other gentlemen present at this meeting, a considerable experience of miners' safety-lamps, and I claim now that there is a great future before the cap type of lamp. For instance, I do not think that the cap-lamp will receive the same abuse that the ordinary standard type of lamp has been subjected to in the past. We all know that the standard type of electric lamp was abused tremendously—I suppose it received that abuse largely because it was capable of standing it. The oil cap-lamp has always been very much in vogue in Scotland, but in England the introduction of an electric cap-lamp is perhaps going to be a different problem. At the same time, I believe that the electric cap-lamp will be used in England, and that very quickly. It was my experience when working in a Midland colliery many years ago to be associated with a plan of the management for the introduction of the Scottish oil cap-lamps. At first a great deal of animosity was shown by the workers towards these lamps. I chanced to be back at that particular colliery just a year ago, and noticed then rather a strange feature—that nearly 90 per cent. of the

* *Trans. Inst. M.E.*, 1920-1921, vol. lxi., page 82; and 1921-1922, vol. lxii., page 37.

men employed there were wearing the little Scottish oil-lamps on their caps. That proves that the utility of the little cap-lamp is at least coming to be recognized on the other side of the Border.

The President: How does the weight of the "Ceag" head-lamp compare, say, with the ordinary miner's small lamp?

Mr. George: The weight on the wearer's head is just the same as the ordinary miner's cap-lamp (4 ounces). The weight of the battery is, of course, extra.

Mr. John C. Blake (Girvan): Speaking on behalf of the "Beam" lamp, it weighs about 3 ounces, and with the cable its weight is $6\frac{1}{2}$ ounces; or with the accumulator and everything else, the total weight is $4\frac{1}{2}$ pounds.

(In reply to questions from Mr. James Hamilton, Mr. George and Mr. Blake demonstrated how the batteries and cables of the respective lamps could be worn so as to give the minimum of inconvenience to users of the lamps while working.)

Mr. Blake: I think it is better to leave the question of how to wear the lamp to be settled by the individual user. I would leave him to carry the accumulator wherever he finds it most convenient for his own personal freedom when working, namely, either at the back, at the side, or in front. I may mention that the Safety Lamps Committee some two years ago sent out a specification for this class of lamp. There was a suggestion then that the accumulator should be carried between the shoulders. I objected very strongly to that when discussing the matter with Dr. Wheeler of the Eskmeals testing-station. I do not know whether my remarks, by way of objection, had any influence or not, but that suggestion does not appear to be insisted on now.

Mr. David Archibald (Dumfermline): Could we have details of the approximate cost of the respective lamps, as well as particulars of the approximate upkeep, and so on? For instance, how long will the lamp burn, and has it to be charged daily?

Mr. Blake: It will burn for 16 hours, and has to be charged daily, if it is desired to keep the accumulator in good order.

Mr. Archibald: It seems to me that the light in the "Beam" lamp is brighter than in the "Ceag" lamp.

Mr. George: I do not desire to raise any controversy in regard to the two accumulators, but if there was a small bulb in the "Ceag" lamp similar to that in the "Beam," a much brighter light would result. One cannot judge the efficiency or otherwise of a bulb by its light, as the bulb and cell must be in harmony or "tune," and one with the other. Overrun bulbs destroy the cell and increase the cost of bulb consumption; and when a bulb is out of "tune" or overrun, the cost of upkeep becomes excessive. The complete cost of the lamp is 36s. I believe it will become cheaper once we reach the stage of mass production, but, as you know, we cannot go in for mass production in the case of new lamps until we have these lamps properly tested.

The President: I am glad that some of our friends across the Border are beginning to realize that there are some virtues in the old Scottish miner's cap lamp. Small as that lamp is, and looked upon often with disdain, it is a lamp that has been found of much use in Scotland, and I

believe it will continue to be so until we get something better. It is a pleasure to hear what Mr. George has to say about the future of the head-lamp, for in the old days some of the Inspectors of Mines—the late Mr. A. H. Stokes was a notable example—had not a good word to say for the Scottish miner's lamp.

The discussion on the paper was closed.

DISCUSSION OF MR. DAVID PENMAN'S PAPER ON "A NEW METHOD OF MEASURING VENTILATING RESISTANCES, WITH SPECIAL REFERENCE TO THE OPERATION OF MINE FANS IN COMBINATION."*

Mr. G. L. Kerr (Glasgow): The author is to be congratulated on placing before the members of the Institute his views on this rather complicated subject of fan ventilation. The latter part of the paper, dealing with the running of fans in combination, will interest especially mining engineers who have problems to deal with similar to those mentioned by Mr. Penman.

In his introduction the author rightly states that the problems arising in connexion with the running of fans in combination are not new, for it is known that the subject has been investigated more than twenty years ago, both in Britain and on the Continent. While Mr. Penman is to be congratulated on the way in which he has dealt with the technical or scientific side of the question, speaking generally, and viewed from the practical standpoint, the paper is rather disappointing. The running of fans in series or in parallel, while probably not widely practised, is fairly common, either by two fans at the surface or by one fan at the surface and auxiliary fans underground, and hence the reason why more prominence should have been given to the practical side of the subject.

Probably Mr. Penman intentionally devoted his investigations to fans situated on the surface, and was of opinion that the question of auxiliary fans underground should be treated separately. A large number of mines have installed auxiliary fans underground, which may be said to work in series with the surface fan, and I am satisfied that in many cases, before installing these fans, investigations should be made as to the suitability and efficiency of the main fan at the surface, and to the condition of the airways underground. In writing his paper, while it may not have been Mr. Penman's chief idea, I take it that his intention was to simplify matters for the student and colliery manager.

With regard to his suggestion as to the unit of resistance, would this be the assistance to the student that the author expects? Would it not rather tend to produce confusion, as a student would require to know the basis of this unit before he could use it, and he would also require to understand the equivalent-orifice method of comparing resistances, so that either the equivalent-orifice method must be scrapped for the direct method of comparing resistances by units, or confusion will result. Probably Mr. Penman does desire the scrapping of the older method, but that desire cannot be realized, as it is necessary that a student should have some knowledge of the equivalent-orifice method.

Then as to the colliery manager, that gentleman is not greatly interested as to whether his neighbour's mine has a resistance of 33·3

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 39.

units so long as his own can be kept down to 3, and the paper might have dealt with some practical suggestions for reducing the mine resistances in the different seams, or districts, as the case may be. To take a case in point: in a mine with three seams, in each of which the water-gauge for the required volume varied considerably, the surface ventilator would then require to set up a depression equal to producing the maximum water-gauge required in any of the three seams, and the other districts with lower gauges would require to be regulated; whereas if the resistance in the three seams could be balanced to suit the minimum water-gauge, a considerable saving in power would be effected.

Generally speaking, the conditions to be met with in practice are rather in favour of fans in series than of fans in parallel. A ventilator may have reached its limit of capacity, and if it is a somewhat out-of-date and inefficient machine, there is then no doubt as to how to deal with it, namely, to replace it with a ventilator capable of giving the increased volume at the increased water-gauge. If, however, the ventilator is of modern and efficient design and in good condition, it may be possible by putting another fan in series to obtain the duty required more economically in first cost than by scrapping the existing ventilator. By putting in an exact duplicate it would be possible, by running the two fans in series, to produce the same volume at double the water-gauge; but in the event of additional volume being wanted—say, 25 per cent. or 30 per cent. more air—the new fan could be designed to deal with this larger volume; and by easing the load on the existing fan, it would probably be possible to pass the extra volume through it at the expense of a slight increase in the resistance through the fan itself, the limiting feature being the capacity of the existing fan to pass the increased volume required.

It is seldom an advantage to run fans in parallel, and cases where this is applicable are undoubtedly where the increased volume is required at practically the same water-gauge. A good example would be in starting a new pit where for developing purposes a fan would be installed capable of giving half the ultimate volume at the maximum water-gauge required. When this fan has reached the limit of its capacity, and the orifice of the mine continues to increase, the other fan would be installed, and the two run at such a speed as to produce the water-gauge required for the volume being passed by the mine, the speeds being increased for higher duties until the maximum is reached.

Another case where fans in parallel are useful is when the full ventilation is not required during the week-end, in which case one fan is capable of circulating a sufficient volume of air to keep the workings clear of accumulations of gas, and the two fans are run in parallel during the remainder of the working week. Where the electric power has to be purchased from a supply company, this arrangement effects a considerable saving in cost of power.

It is to be regretted, therefore, that the author did not give separate tests of each of the fans and plot curves giving the efficiencies through the various range of tests on the existing orifice of the mine, and also on the orifice for which the fans were designed by the makers, instead of experimenting with variations in speed in order to see how one fan would motor the other.

I am also disappointed at the terms of some of the conclusions. No. 3 states that unless the resistance of the fan is at least one-third of the resistance of the mine, the advantage of running two fans in parallel is small. From a practical point of view no mining engineer would think

of installing a fan with a resistance equal to one-third of the resistance of the mine, as the work required to overcome the internal resistance of the fan would form far too high a proportion of the useful work in producing ventilation.

Conclusion No. 4 states that if the resistance of the fan is small, compared with that of the mine (and this is as it ought to be), the increase in quantity by parallel operation will be small. If an increase in quantity is required, it will not be got efficiently by putting two fans in parallel and running them at the same speed, and unless the speed of both fans can be increased, so as to obtain the increased water-gauge to produce the extra ventilation required, it would be better to scrap the paralleling idea and put in a new ventilator designed to suit the orifice of the mine.

With regard to conclusion No. 5, that if increase of quantity is the sole desideratum, better results will in most cases be obtained by combining the fans in series than by running them in parallel: as already pointed out, the increase in quantity can on a given orifice be obtained only by increasing the water-gauge, and the limit of increase is determined by the capacity of the existing fan to pass the extra volume of air produced by working the two fans in series—that is, on the assumption that the second fan is installed to assist an existing fan.

Conclusions Nos. 6 and 7 are at least debatable. Mr. Penman, in giving an increase of 35 per cent. by running fans in series, puts the figure higher than most authorities. To accept such a statement might be misleading, as it would be necessary to know all the facts in each particular case before stating definitely any increased percentage, and the design of the fan would have an important bearing upon the effect produced by running fans in parallel.

Mr. Penman states that the increase in quantity of air by running two fans in parallel will vary between 5 and 15 per cent. That will only be true of certain types of fans; with other types, such as the Guibal, it would probably be found that practically no increase at all would be obtained.

The author states that both fans have a rated capacity of 200,000 cubic feet per minute at a water-gauge of 4 inches. Subsequently he states that the Sirocco fan is designed to work on a mine having an equivalent orifice of 56·67 square feet, and the Waddle fan for working on mine equivalent orifices of 45 to 75 square feet. I was surprised that a Sirocco fan 119 inches (approximately 10 feet) in diameter, designed for an equivalent orifice of 56·67 square feet, should have so low-rated a capacity as 200,000 cubic feet per minute at a water-guage of 4 inches, and I communicated with the makers, who informed me that the fan has a rated capacity of double that quoted by Mr. Penman, both as to quantity and water-gauge!

Mr. Sam Mavor remarked at the last meeting that it would add more to the value of papers like this if these tests were made on some standard basis, a remark with which most engineers will agree. A paper was read before the Institute in 1913 by Mr. John Watson on "The Testing of Fans: A Plea for Standardized Test Conditions,"* and as a result of that paper the Mining Institute of Scotland appointed a Committee to fix on a standard method of test conditions, but unfortunately, owing to the war breaking out, practically nothing was done. Now that more peaceful times have come, it is to be hoped that attention will again

* *Trans. Inst. M. E.*, 1912-1913, vol. xlv., page 403.

be given to the matter. If a standard could be laid down, then Mr. Penman's advocacy of the unit method of comparing the relative resistances might be adopted.

In his tests of the two fans the author might with advantage have standardized some of his results. Take, for example, tests Nos. 8 and 9. Here he made a test of each fan running separately, but in the two tests he has different peripheral speeds of the fans. Test No. 8 gives the Waddle fan as running at 125 revolutions per minute, or a peripheral speed of 137·77 feet per second, giving 114,310 cubic feet of air per minute at a water-gauge of 4·2 inches; test No. 9 gives the Sirocco fan running at 172 revolutions per minute, or a peripheral speed of 90 feet per second, giving 111,986 cubic feet of air per minute at a water-gauge of 4·1 inches. Mr. Penman explains in a foot-note that he chose the speed of 125 revolutions for the Waddle fan because it was the speed at which it would share the air nearly equally with the Sirocco fan at 172 revolutions per minute. That was a good enough reason, perhaps, when the two fans were running in combination, but it does not give the information one would desire when the fans were running singly. If Mr. Penman had adopted a standard peripheral speed—say, 1,000 feet per minute—for both fans in these two tests, some interesting information as to the output capabilities of the two fans in regard to quantity and water-gauge would have resulted.

Mr. Penman must have devoted a great deal of time and labour in obtaining the data for his paper, and we are much indebted to him for bringing so interesting a communication before the Institute.

Mr. R. W. Dron (Glasgow): Mr. Kerr has brought out in his remarks a point that I personally happened to encounter a year or two ago in dealing with a colliery. The conditions were just as he has explained, with one of the sections very badly ventilated. The distance from the face of that section to the pit-bottom was $1\frac{1}{2}$ miles, and the other sections were comparatively near the pit-bottom. The fan speed had been increased and the water-gauge increased, but it was impossible to send sufficient air into this section $1\frac{1}{2}$ miles distant. I installed a small auxiliary fan, with the result that the whole difficulty was removed. I may add that the increase in the water-gauge was causing so much pressure in one of the intake return air-courses that it was creating an incipient underground fire. I consider we are much indebted to Mr. Kerr for putting these points before us.

It is in discussing problems like these that I think our younger members especially ought to assert themselves. I am sure that they must have had experiences in working which would throw light on a number of interesting questions, in addition to the one dealt with for setting up standard tests. I consider it would be a good thing if the Institute were to revive the Committee of enquiry in regard to fan efficiency. There are one or two members of the Institute who have an expert knowledge of this subject, and I think that the other members are entitled to get the benefit of their views and experiences.

Mr. G. L. Kerr: I agree with Mr. Dron that this is a point which should be taken up by the younger members of the Institute. I have been asked over and over again where I considered was the best point to introduce an auxiliary fan underground, and that is just the question I would like the younger members to consider. Theoretically speaking, I, of course know what is considered the best place to put an auxiliary fan, but the difficulty arises whether or not it is practicable to locate it at

that point, namely, where there is equilibrium of water-gauge. Theoretically, the point where equilibrium of water-gauge can be secured is admitted to be the most desirable place, but it is sometimes difficult to say whether that is, under all conditions, the most suitable. It is here that the younger members of the Institute could be of assistance in submitting their views and opinions.

The PRESIDENT (Mr. Robert McLaren, M.P.): I feel it is a great pity that this Committee of the Institute which was formed some years ago did not function, but that, as we all know, was due to matters over which we had no control. In view, however, of what has been said to-day by Mr. Kerr, I think it is absolutely necessary that this Committee should be set up again in an endeavour to reach the facts.

I am not so sure that I agree with all the objections that have been raised respecting auxiliary fans. In my opinion there is a great deal about the surface that is at fault. Take the case of a mine where surface plant has been laid down and a shaft sunk: in course of time certain things happen which it was not expected would occur, and the management are faced with the necessity of sending through a larger quantity of air. That can be done in no other way than by the use of auxiliary fans, and it is not always easy to foresee in mining practice just what is going to take place in the future. It has always seemed to me that the man who introduced the first auxiliary fan into mining in Scotland was looking wisely ahead. It is for the younger members of the Institute to tackle this question, and to go into it thoroughly.

The further discussion of the paper was adjourned.

THE TESTING OF ANEMOMETERS.

By JAMES COOPER.

Introduction.—The two best-known methods of measuring air-velocities in mines, namely, by the anemometer and by means of smoke, are both liable to serious error. As has been frequently noticed, smoke travelling in an airway of uniform section is subject to a decrease of velocity as it passes onwards from the point of ignition: in the central part of the roadway it is affected by eddies; at the sides it clings to damp surfaces, and is seriously impeded by timber. If the sectional area of the road varies, the results obtained by smoke are still more faulty.

Because of the friction of its parts, the anemometer, too, can yield an accurate result only at one velocity; at all others accuracy can be achieved only by correcting for the influence of friction, and at low velocities the correction may be greater than the speed registered by the instrument.

Despite its delicacy and liability to damage in inexpert hands, the anemometer is likely to retain the leading place as a means of measuring air-velocity, and in view of its frequent use in carrying out Section 29 of the Coal Mines Act, 1911, and of the importance of its duties in fan-testing, it has been considered advisable to provide at the Heriot-Watt College, Edinburgh, the means of testing these instruments. The main purpose of this paper is to discuss the results furnished by the testing-"table" that has been installed there, and to compare them with those obtained in other ways.

That there is need for a readily-accessible means of calibrating anemometers is clear from the fact that at the National Physical Laboratory, Teddington, anemometers are not tested at velocities lower than 600 feet per minute, while air-speeds under that figure are common in mines. It is, indeed, for velocities below 300 feet per minute that the need for calibration becomes most imperative, and it is especially at these low speeds that the effect upon the instrument of wear and rough handling is most pronounced. In order to obtain accurate results with this instrument, then, it should be re-tested at definite intervals—say, every year—as well as after repair; the makers' chart, if assumed to be correct, should be held to apply only for a limited time; and special attention should be paid, in testing, to velocities under 300 feet per minute.

The unreliability of an inadequately-tested instrument has been referred to recently in an important paper read before the Institution,* in which the following statement is made:—

"Owing to the gross inaccuracy of anemometer readings at low speeds, the figures for the speeds of air at Pendleton cannot be relied upon within 100 per cent. error."†

* "Third Report of the Committee on 'The Control of Atmospheric Conditions in Hot and Deep Mines': Observations of Temperature and Moisture in Deep Coal-mines," *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 101.

† *Ibid.*, page 112.

In this paper, I shall not deal with the accuracy of air-measurements taken by the Pitot tube, as the matter has been exhaustively treated in a paper by Dr. A. Rateau.*

The Anemometer Table.—The "table" may be regarded as a development of that described almost sixty years ago by J. J. Atkinson

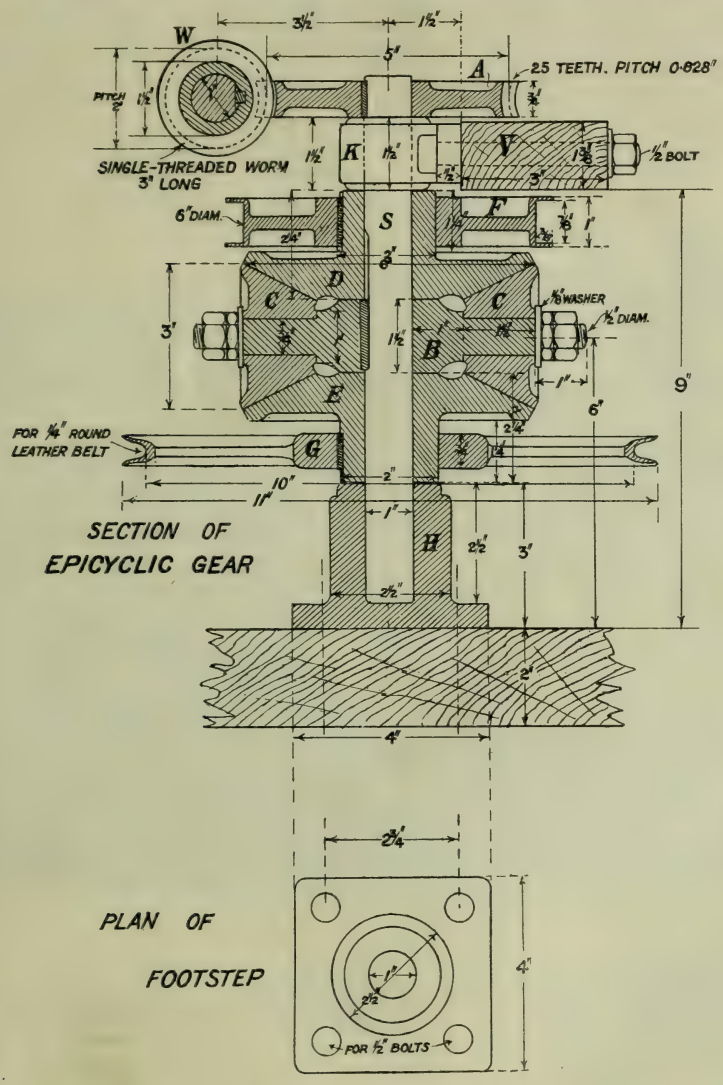


FIG. 1.—SECTION OF EPICYCLIC GEAR AND PLAN OF FOOTSTEP. SCALE, ONE-QUARTER ACTUAL SIZE.

and J. Daglish.† It has been designed by Dr. Henry Briggs, and is illustrated by the accompanying drawings and photographs (Figs. 1 to 9).

* "Experimental Investigations upon the Theory of the Pitot Tube and the Woltmann Mill," by A. Rateau, *Trans. Inst. M. E.*, 1898-1899, vol. xvii., page 124.

† "The Velocities of Currents of Air in Mines," *Trans. N. E. Inst.*, 1861-1862, vol. x., page 207.

The whirling rod on which the meter under test is mounted is rotated by means of a leather sewing-machine belt, $\frac{1}{4}$ inch in diameter, from a special driving gear (Figs. 1 and 2). Owing to the very wide range required, it was decided to adopt a mechanical rather than an electrical arrangement for obtaining different speeds.

The variable-speed gear, which is worked from a shunt-wound motor through a worm and worm-wheel, is of the epicyclic type. The vertical bevel-wheels *D* are carried round at constant speeds; they engage with

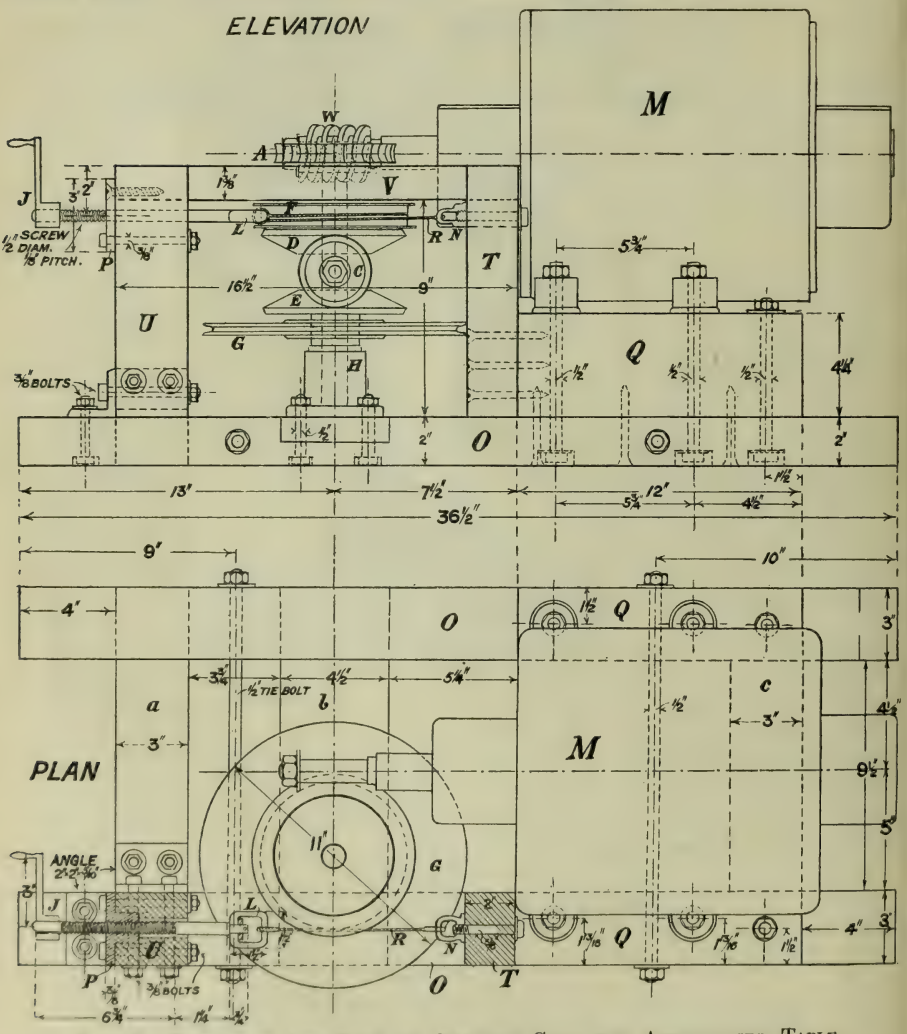


Fig. 2.—Elevation and Plan of Driving Gear for Anemometer Table. Scale, One-eighth Actual Size.

the horizontal bevels *C* and *E*, of which the latter is in one piece with the brake-wheel *F*. The brake is a motor-cycle belt, and is adjusted by the screw and handle *H*.

Tightening of the brake causes *C*, and therefore the driving-pulley, to rotate at a higher speed. By this means the rod can be whirled at any rate between 5 and 70 revolutions per minute, and this speed can be quickly and easily changed. Both the motor and gear are mounted on a wooden frame; they occupy little space, and are very portable.

The framework on which the whirling rod and small motor is mounted (Fig. 3) was also designed to be portable, so that the apparatus can be moved aside after completing a test. The rod is of Chesterfield steel tubing, No. 21 gauge, 2 inches in diameter, 12 feet long, and weighs 8 pounds. It combines lightness with rigidity. A simple clamp (Fig. 4) fixes the meter to any part of the rod.

A novel feature of the apparatus (Fig. 4) is the manner of operating the meter-trigger or clutch while the meter is being carried round on the rod. In order to ensure accuracy in calibrating an anemometer, it is essential that the meter should be moving at the selected speed before the counting mechanism is put into gear, and also after the lapse of the required interval that the mechanism should be thrown out of gear while the meter is moving.

These requirements entailed the use of some means which could be instantaneously operated from outside the radius of the moving rod,

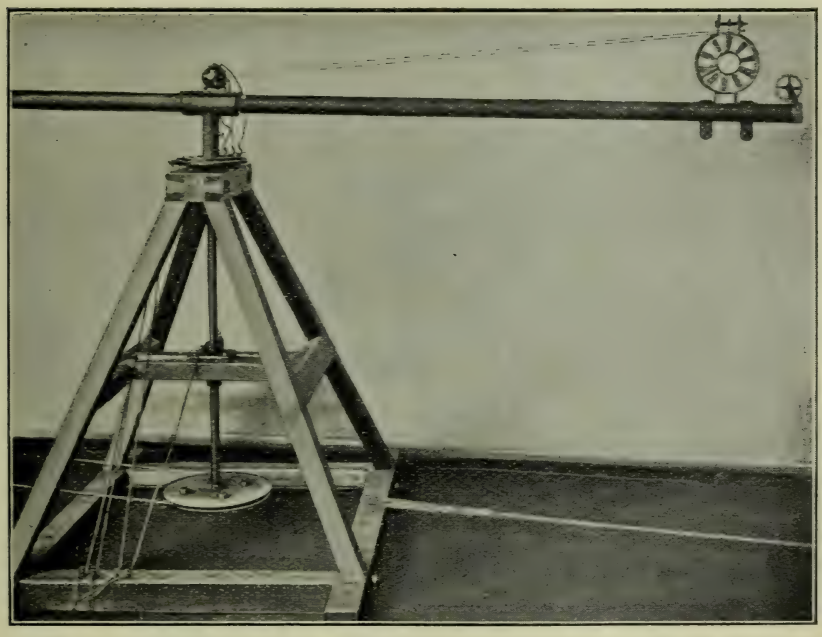


Fig. 3.—Framework containing Whirling Rod and Small Motor.

and it was decided to adopt an electrical device to secure the instantaneous action required.

A small motor is mounted on the brass table (Fig. 3), and a light drum, $\frac{3}{4}$ inch long and $\frac{1}{2}$ inch in diameter, is fixed to the motor-shaft. A thread is passed from the meter-trigger round the drum in a single loop, thence to a small pulley fixed on the meter clamp, and back to the trigger (Fig. 4). The motor is shunt-connected, and takes current from a 4-volt battery working through a switch with forward, off, and reverse positions. The motor terminals are connected to three contact-brushes running on a three-ring disc, and the fourth wire is connected to the vertical shaft. The rings and shaft are in turn connected to the reversing-switch. In one position of the switch the motor draws the thread and throws in the counting gear; in the reverse position it throws it out. An advantage of the appliance is that it works on a slack thread, which, therefore, requires no precise adjustment of length.

The arrangement is found to work perfectly, and in numerous tests the results have been recorded throughout with no failure of action of the motor, the trigger in all cases acting instantaneously.

In order to ensure that the revolving meter will meet the air in a fairly straight path, the brass casting connecting the whirling rod to the vertical shaft is so designed that the rod can be slipped along and fixed at a large radius.

Numerous tests have been carried out on this anemometer table, and the figures obtained from the experiments have been compared (1) by observations of smoke velocities, and (2) by walking tests with the meters over a measured straight line in a still atmosphere. It will be noted from the graphs (Figs. 5, 6, 8, and 9) that the results are reasonably consistent.

The meters used were of the Biram type, this being the instrument most in favour in the mines of this country.

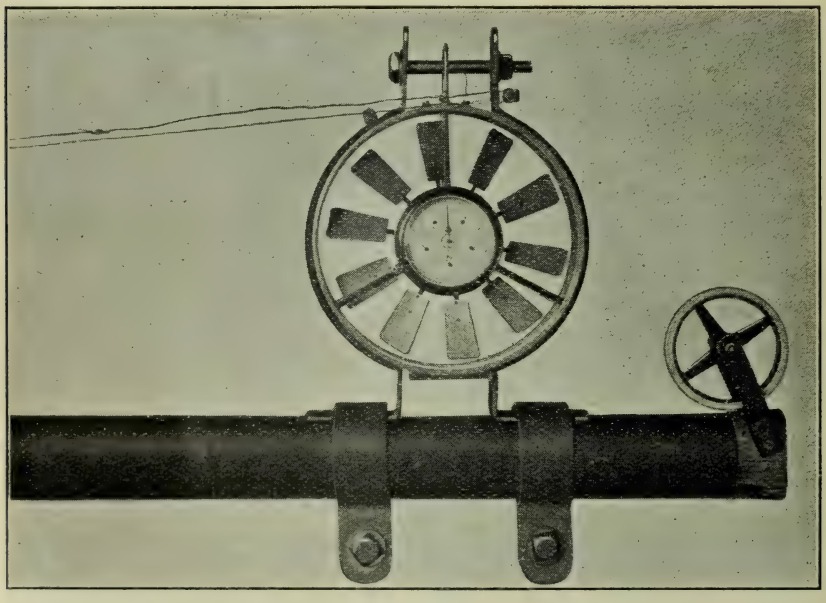


Fig. 4.—Method of Operating the Meter-trigger.

Experiments with the Anemometer fixed at Different Radii on the Rod.—The first series of tests carried out was with the object of discovering what influence, if any, would result by fixing a meter on the rod at different radii. These radii varied between 6½ feet and 1 foot. It was to be expected, at short radius where the whirling anemometer was not moving through the air at a uniform velocity at all points of its width, that the results as indicated by the instrument would be affected thereby, and the tests proved this to be the case.

As shown by the appended curves (Fig. 5), the results obtained at the larger radii were fairly consistent with straight-line walking tests, which will be described later. It will be observed that the correction chart for the greatest radius crosses the zero-line at a greater velocity than the other curves, but for velocities between 500 and 2,000 feet, the latter being the maximum achieved, the correction at all radii is approximately the same.

The series of results shown in Fig. 5 was obtained with a 6-inch anemometer; this series was then checked by using a $2\frac{3}{4}$-inch instrument, and a similar set of records was taken (Fig. 6). Again, the curves from the readings taken at the smaller radii cross the zero-line at the

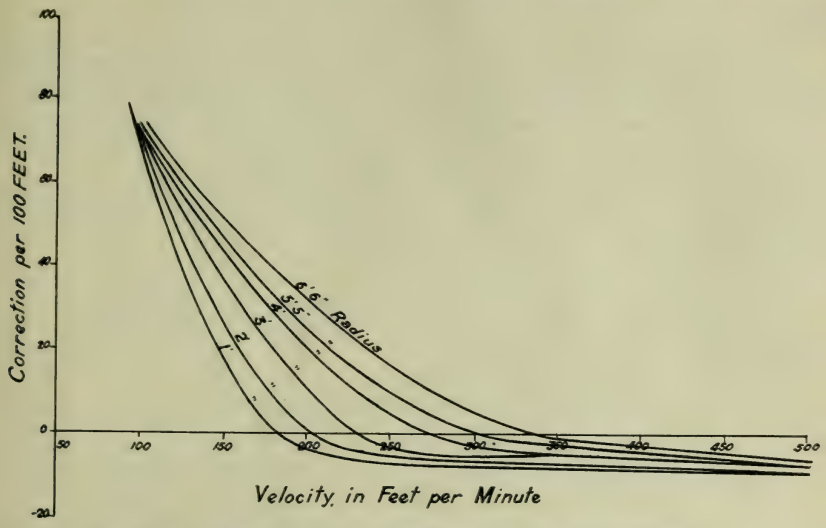


FIG. 5.—CHARTS OF 6-INCH ANEMOMETER AT DIFFERENT RADII.

lower velocities, and the regular ascending sequence of curves was obtained when the meter was fixed at successively greater radii in a manner similar to the previous set (Fig. 5).

The differences in the corrections got from the results obtained by

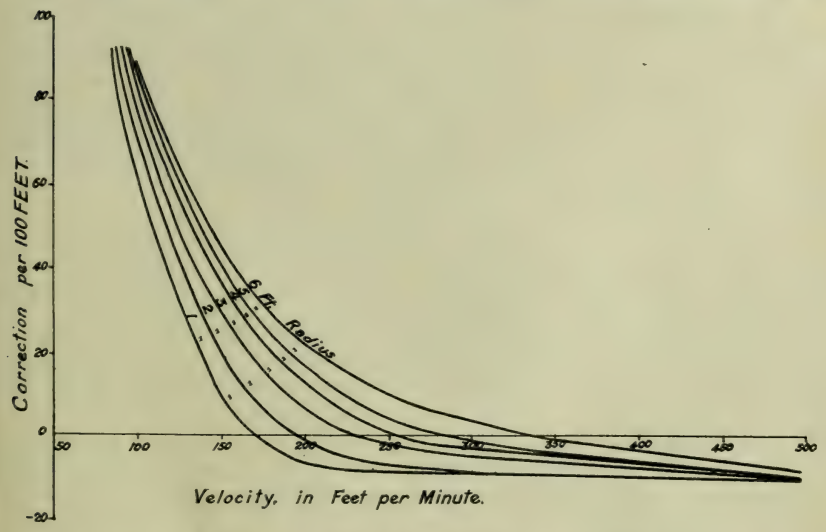


FIG. 6.—CHARTS OF $2\frac{3}{4}$-INCH ANEMOMETER AT DIFFERENT RADII.

placing the meter at different radii on the whirling rod are so considerable that it was deemed necessary to enquire into the reason for that difference. Dr. Briggs suggested that the effect might be explained from the fact that the impact of the air across the width of the fan differed

most with the small radii. He made the following calculation to ascertain whether that influence would explain the observed results :—

Fig. 7 represents an anemometer fixed on the rod at a given radius, R feet.

P is a point at the centre of a vane.

$r = r_1 - r_2$.

The kinetic energy given to an elemental strip of the vane at the point P, where the speed of rotation is constant, $= k(R - r \sin a)^2 \, da$; where a is the angle between the vane and any fixed arbitrary position, in this case, the vertical, and where k is a constant.

Total $K.E.$ (kinetic energy) given to wheel $= k \int_0^{2\pi} (R - r \sin a)^2 \, da$

$= k(2\pi R^2 + \pi r^2)$.

Let V_1 be recorded velocity

V be the velocity corrected for effect now under consideration.

But $V^2 \propto K.E.$

Velocity recorded $= \sqrt{k(2\pi R^2 + \pi r^2)}$.

It can be shown that $K.E.$ given to wheel $= k(2\pi R^2)$.

$V^2 = 2\pi k R^2$ and $V_1^2 = k(2\pi R^2 + \pi r^2)$.

$$\frac{V_1^2}{V^2} = \frac{2\pi k R^2 + \pi k r^2}{2\pi k R^2} = 1 + \frac{r^2}{2R^2}.$$

Applying the result arrived at in the foregoing calculation to the several radii, it was, however, found to be inadequate to explain the difference determined by experiment.

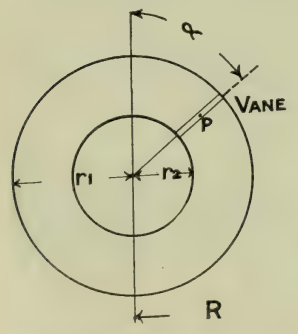


Fig. 7.—Anemometer fixed on Whirling Rod.

This point was also discussed in the before-mentioned paper by J. J. Atkinson and J. Daglish, the circles selected in their experiments being 10 feet and 25 feet respectively in circumference. The results recorded by these writers are similar to those enumerated in this paper. Another cause, and one much more pronounced, must, therefore, be sought for, and the following explanation is suggested :—

The probable effect of air striking the vanes of a meter is to set up certain stream-lines which pass on either side; the deflection of these stream-lines tends to create a partial vacuum behind the vane. By varying the position of the meter—for example, at different radii on the whirling rod—the stream-lines deflection will vary, and, according to the results of the experiments described, the vacuum effect seems to increase as the circle of travel decreases.

But, as already mentioned, the chart correction is practically uniform for all radii at a velocity of 500 feet; the vacuum effect seems to stabilize at this point, and the meter to move through a path of uniform stream-lines.

In the paper by Dr. Rateau similar experiments were carried out and differences in the results recorded. In his paper the author mentions the difficulty of explaining the cause of the differences in the results.

In using an anemometer table, the problem is one of considerable importance, and is closely bound up with the general principles of aerodynamics.

Comparison of Different Anemometers.—The following series of tests was carried out in order to obtain charts for different sizes of instruments, and 6-inch and 4-inch meters of similar design were used (Fig. 4), while two $2\frac{3}{4}$-inch meters of the usual design were also included.

The four anemometers tested were all in regular use—one $2\frac{3}{4}$-inch and the 6-inch at the Heriot-Watt College and the 4-inch and the second $2\frac{3}{4}$-inch at collieries.

The radius selected at which to place the meters was 5 feet 5 inches, giving a circumference of travel of 34 feet, and the speeds recorded ranged from 50 to over 2,000 feet per minute.

As the first-mentioned velocity is very low for anemometer reading, it was found during the tests that only instruments in good working order would give satisfactory results at that speed. Of the four anemometers tested, only the 4-inch and 6-inch meters yielded consistent figures at

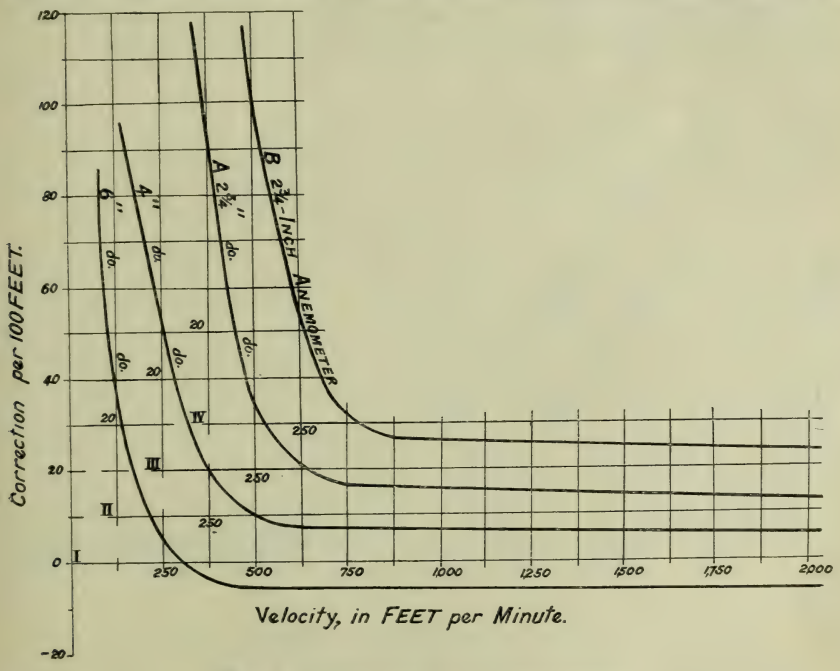


FIG. 8.—CHARTS OF FOUR ANEMOMETERS.

this low rate of speed; this was probably due to the former being a new instrument and to the latter having lately been overhauled.

The results given by the two small instruments were unreliable, and required unworkably large corrections at low speeds.

When a velocity of 500 feet per minute is reached (Fig. 8), the corrections for all four instruments become fairly uniform, and remain so up to the maximum velocity of over 2,000 feet per minute.

An interesting point in connexion with those experiments is that, although the charts plotted from the tests are similar in form to those sent out by the makers of the instruments, the figures of correction differ widely. This is particularly so at low speeds, and also at the recorded velocities of crossing the line of zero correction.

In these experiments the effect of impact of the air due to the mass of the rod and meter has been neglected, as it was considered that a correction for this effect would be very small. Dr. Rateau points out

that a rod with a sharp edge facing the direction of movement would eliminate the effect of impact. This, however, could be gained only at the expense of rigidity of the rod, and bending of this part of the table would introduce serious errors in the results.

Determining the Air-velocity by Means of a Smoke-cloud.—The errors associated with the use of smoke as a means of measuring the air-velocity were thoroughly investigated many years ago by J. J. Atkinson and J. Daglish,* and I have referred to these errors in the introductory part of this paper.

After a series of tests, in which the velocities of air-currents were determined in a smooth-sided experimental gallery, first by the four calibrated anemometers and then by means of smoke, it only requires to be said that the latter method proves to be unreliable. It has achieved a spurious importance of late years, due to its introduction into the Home Office mine-firemen's examination; but for that, it would probably by now have passed into the oblivion it so well deserves.

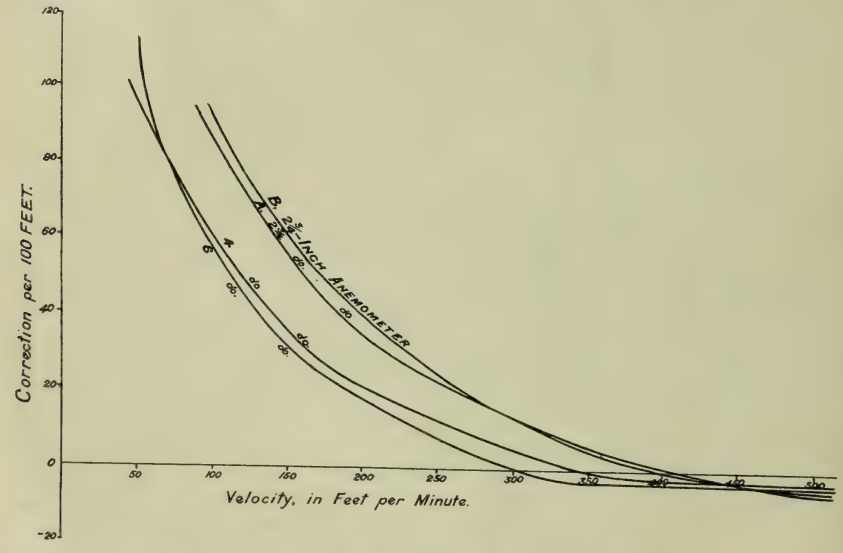


Fig. 9.—Charts of Anemometer Walking Tests.

Walking Tests with Anemometers.—The last series of tests undertaken was to calibrate the anemometers by holding the instrument in the hand and walking in still air over a measured distance. A suitable place for this purpose was found in the observation-court at the mine-rescue station of the College, and the procedure adopted was as follows:—

A straight path 66 feet long was measured, and timed readings of the instruments were taken over this distance. A few paces were traversed before the starting-point was reached; then the meter and stop-watch were thrown into gear simultaneously. The distance was traversed in times varying from 5 to 40 seconds. When low velocities were being measured in this way, the inertia of the older instruments required to be overcome by a tap at the start; the vanes would then continue to revolve throughout the measured distance.

The carrying-out of these walking tests involves the obvious difficulty

* *Loc. cit.*

of obtaining a sufficiently long straight path in still air; in my tests, if a longer distance than the 66 feet had been taken, it would have necessitated turning through several sharp bends, and errors of unknown magnitude might have resulted from the frequent change of direction.

The lowest speed selected was that just sufficient to cause the vanes to revolve. This was obtained when walking at a speed of 99 feet per minute, and at this rate the reading in the two small anemometers was about 30 feet per minute. This results in a plus correction of over 200 feet per 100 feet per minute.

Experimental errors that are likely to occur are those due to jolting of the instrument while running, and to the possible production of a swirl in the air by the body passing through it.

The value of this series of tests (Fig. 9) is a measure of the approximation of the correction curves to those obtained from the whirling rod; and on comparison of the plotted results from both series, it will be noted that the values are fairly consistent throughout the respective charts.

This conclusion is of value, for, given a straight path in still air and a reliable stop-watch measuring to a fifth of a second, it is seen to be possible, without more elaborate mechanism, to determine the correction curve for an anemometer for speeds up to 500 feet per minute with a degree of precision sufficient for ordinary purposes.

Conclusions.—The results obtained in these tests indicate the unreliability of the anemometer when measuring low air-velocities. In the roads close to coal-faces we have to deal with speeds which are often low; in those circumstances the values obtained direct from the anemometer and without correction are entirely fallacious. Yet it is just at such places in a mine that, in everyday practice, the instrument should be of most service, for we have especial interest in knowing accurately the volume of air that reaches the working-faces.

In the preparation of this paper I have received many helpful suggestions from Dr. Henry Briggs; I also wish to record my indebtedness to Mr. J. Wilson and Mr. R. A. Moffat, of the Mining Department of the College, for their assistance in the experimental work.

THE SOUTH STAFFORDSHIRE AND WARWICKSHIRE INSTITUTE OF MINING ENGINEERS.

FIFTY-FOURTH ANNUAL GENERAL MEETING,

HELD AT THE UNIVERSITY, EDMUND STREET, BIRMINGHAM, OCTOBER 10TH, 1921.

MR. J. R. FELTON, PRESIDENT, IN THE CHAIR.

DEATH OF SIR FRANCIS BRAIN.

The President proposed a vote of condolence with the relatives of the late Sir Francis Brain, who was for many years a member of the Institute. The vote was passed in silence, the members standing.

Mr. J. R. Felton was unanimously re-elected President for the ensuing year.

INCREASE IN SUBSCRIPTION RATES.

The President, in thanking the members for the honour which they had done him in re-electing him as President for another year, stated that the Council had decided to raise the subscription rates as follows :— Members and Associate Members, £2 12s. 6d.; Associates and Students, £1 11s. 6d.; Subscribers, £1 7s. 6d. The new rates would not, however, come into operation until the year 1922-1923.

ELECTION OF MEMBERS.

The following gentlemen, having been approved by the Council, were elected :—

ASSOCIATE MEMBERS—

Mr. J. E. LLOYD, Walsall Road, Aldridge, Walsall.

Mr. C. E. HIGLEY, Marikuppam P.O., Mysore, South India.

ABSTRACT OF FIFTY-FOURTH ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

Four General and four Council Meetings have been held during the past year. Meetings that were to have been held in April and June were abandoned on account of the coal strike.

The Council is disappointed to note that there has been no improvement in the attendance at meetings, and would point out that the continued success of the Institute is dependent on much greater enthusiasm being shown by the individual members.

The position of the Institute continues to be satisfactory. The number of members on the register is 164, as against 155 for last year. Eighteen new members have been elected, 3 have died, 1 has resigned, and 5 have been struck off for non-payment of subscriptions.

The Council regrets to record the death of Sir Gilbert Claughton, Bart., and of Mr. Arthur Sopwith, both Past-Presidents of the Institute,

The South Staffordshire and Warwickshire Institute of Mining Engineers: Abstract of Balance-sheet, July 31st, 1921.

Liabilities.

	£	s.	d.	£	s.	d.
Sundry creditors				89	0	0
Subscriptions paid in advance				24	3	0
Income-and-Expenditure Account—						
Balance at July 31st, 1920 ...	653	11	7			
Less Excess of expenditure over income for the year	12	9	0			
				641	2	7
Entertainment Fund				16	0	7
				£770	6	2

Assets.

	£	s.	d.
Cash at bank	164	10	8
Subscriptions outstanding	21	0	0
£500 War Savings Certificates (at cost)	387	10	0
£200 5 per-cent. National War Bonds ...	197	5	6
	£770	6	2

Abstract of Income-and-Expenditure Account for the Year ended July 31st, 1921.

Expenditure.

	£	s.	d.
To The Institution of Mining Engineers	188	19	5
,, Secretary's salary and audit fee	55	5	0
,, Office rent, cleaning, etc.	10	0	0
,, Printing and stationery	34	16	1
,, Petty cash, postages, etc.	16	1	0
	£305	1	6

Income.

	£	s.	d.
By Subscriptions and entrance-fees	283	19	0
,, Bank interest	3	13	6
,, Interest on £200 5-per-cent. National War Bonds ...	5	0	0
,, Balance, being excess of expenditure over income for the year	12	9	0
	£305	1	6

We have compared the foregoing Balance-sheet and Income-and-Expenditure Account with the books and vouchers of the Institute, and certify them to be in accordance therewith.

Frank Impey & Co.,
Chartered Accountants.

the latter being one of the founders of The Institution of Mining Engineers; also of Mr. W. H. Whitehouse, who for many years acted as one of the Honorary Auditors.

The balance-sheet shows a loss on the year's working of £12 9s. 0d., this loss being accounted for by the increased Call paid to the Institution, and to the printing of circulars, etc. With a view to avoiding a similar deficiency in the future, the question of raising the subscription rates has been considered by the Council.

Four important papers have been read and discussed during the past year.

An arrangement has been arrived at between The Institution of Mining Engineers and The Institution of Mining and Metallurgy whereby the office staffs are amalgamated. This should effect a saving in working costs, and be of considerable advantage to both Institutions.

The thanks of the members are due, and are hereby tendered, to the authorities of the Birmingham University for providing rooms for the meetings of the Institute.

TENSION IN WINDING-ROPES.

By J. STONEY, B.Sc. (Eng.).

Introduction.—On June 16th, 1908, Mr. Joseph Hindley and I communicated to the Manchester Geological and Mining Society a paper entitled "Description of a New Patent Appliance for Arresting the Descent of Cages in Shafts, in the Event of the Winding-rope Breaking."* Springs are used in this appliance, and during the discussion of the paper we were asked whether we had taken into account the variations in the stresses which came on the winding-rope during the period of a wind. We produced an indicator and some stress-diagrams taken by it, in order to show that the springs in our appliance could not come into action during the ordinary process of winding. As the registration of the stresses in winding-ropes was, at that time, only secondary to the problem we had then in hand, namely, the invention of a safety appliance for mine cages, the subject was not considered of prime importance. The Society, however, showed great interest in our appliances, and asked us to persevere in our work, which has led me on several occasions to consider how best to obtain a correct copy of the stresses induced in winding-ropes at mines. I will now examine the stresses which come on the rope according to known mechanical laws.

Most students of the subject will know that during the ordinary process of winding at a mine there is a constantly changing load on the winding-rope. Calculations for the stresses on the rope can be made, in some instances, with a fair degree of accuracy; but at many points in the wind the engineer has to form some judgment of what is really happening to the winding-rope. There is, also, the human element to be taken into account, for the careful winder is not always at the lever.

Commencing with the descending cage from rest, let W equal the weight of the cage and its contents, plus the weight of the rope from the pulley; let a be the acceleration in feet per second; and let F equal the force necessary to produce this acceleration. Then $F = Wa \div 32{\cdot}2$. If

* *Trans. Inst. M. E.*, 1907-1908, vol. xxxv., page 698.

W is in tons or pounds, F will be in tons or pounds respectively. The load on the rope at the pulley will be $L = W - (Wa \div 32{\cdot}2)$.

From this equation it will be seen that the factor which decides what load is on the rope is the acceleration. If $a = 0$, then W is the load on the rope. As a increases, L will decrease; and if a ever becomes equal to 32·2, then L will equal zero. I do not assume that a will often equal 32·2, for this is the acceleration of a freely-falling cage, although in many cases I have seen a sagging rope behind the pulley. The acceleration does not remain uniform, and the value of W increases every moment; therefore, in order to make this calculation, W would have to be ascertained and the value of a would have to be obtained. Under present conditions a could be obtained over a small interval of time, and if the values of W and a are substituted in the foregoing formula, the load on the rope may be ascertained.

It is instructive to observe that the value of a so found is not an instantaneous one, and therefore the value of L will be an average one over the period taken. As a is not an instantaneous acceleration, this means that it is not the acceleration for an "instant." It must be observed from the outset that an "instant" is not what in ordinary language it is supposed to be—that is, an interval of time of indefinite length. It is not an interval of time at all: an instant merely marks the end of one period of time and the beginning of the next. For example, the piston of the winding-engine goes "into" the cylinder, and at the end of the stroke it commences to come "out." The piston does not remain at rest for an interval of time at the "end" of the stroke; the travel of the piston outwards begins just when the travel "in" terminates. Thus an "instant" is the "dividing-point" between two intervals of time.

The difference between an "average" force and an "instantaneous" force is very great. In punching holes in iron plates and in the practice of shearing metals by a shearing-machine we speak of the "average" force of the blow; but the metals are ruptured at the first "impact" of the blow.

This special note upon instantaneous forces is necessary, as in the ordinary course of winding these forces come upon the rope regularly, and in giving this paper it is with the object of obtaining an accurate knowledge of the stresses in the rope. The acceleration in the wind continues until we get to the maximum speed, and the cages may continue at a uniform speed for some distance.

Uniform Speed.—At uniform speed, the average load on the rope is W. Since W represents the weight of the cage and contents, plus the weight of the rope, it follows that the load on the rope increases during the descent at uniform speed, for the length and weight of the rope are increasing.

Application of Brakes.—At a point in the wind the brakes are applied. From this point until the cage is brought to rest is the period of the wind on the descending side in which there is a greater load than W on the rope. In this period there is a retardation; if f represents that retardation, the force necessary to produce it is given by the equation $F = Wf \div 32{\cdot}2$. The load on the rope will now be $L = W + (Wf \div 32{\cdot}2)$. If the retardation f were constant, this calculation would give us the load on the rope upon inserting the value of W.

But engineers who are accustomed to riding on the rope will know that the retardation is not uniform. Upon the application of the brakes, the cage commences to vibrate just as does a weight if hung on a spring.

The more suddenly the brakes are thrown against the engine, the greater the vibrations will be. In the " rebound " at the " instant " when the cage is at the end of the amplitude of vibration a lash is given to the rope. It is at these " instants " that great stress comes in the rope, especially if a loaded cage is descending. The motion of the cage during these vibrations is one compounded of the descent, with a retardation and a vibration in the same direction.

A calculation as a guide to what load comes on the rope due to the vibration may be made as follows :—Let x = the amplitude of vibration, and F = the force necessary to overcome the acceleration at the end of a vibration. Then— $F = \frac{(2\pi)^2}{T^2} \times \frac{Wx}{32{\cdot}2}$.

W = weight of cage plus one-third the weight of rope unwound.

Or $F = \frac{40}{32{\cdot}2} \times \frac{Wx}{T^2}$; where T represents the time of a complete vibration in seconds.

Proof that only one-third the weight of the rope unwound is added :—

Let wds = weight of particle of rope.
" V = vibration velocity of cage.
" v = " " particle wds.
" s = distance of particle from support.
" L = total length of rope unwound.

Then $v = \frac{s}{L} V$.

Kinetic energy of element $= \frac{wds}{2g} \times \frac{s^2}{L^2} V^2$.

$\therefore$ Total kinetic energy of rope $= \frac{wV^2}{2gL^2} \int_0^L s^2.ds$.

For example : " " $= \frac{wV^2}{2gL^2} \times \frac{L^3}{3}$.

That is : " " $= \frac{V^2}{2g} \times \frac{wL}{3}$.

And $\frac{wL}{3}$ is one-third the weight of the rope unwound.

The periodic time will not remain uniform for all the vibrations; it will increase from the commencement of vibration. One can easily observe that the stiffness of the rope decreases as the length of the rope unwound increases, for the stiffness varies inversely as the length.

The time of vibration varies inversely as the square-root of the stiffness; hence the time of vibration varies as the square-root of the length of the rope unwound from the drum. At the end of the descent an uncommon load may come on the rope, as sometimes the winder has to pull up quickly in order to deck the cage.

Ascending Cage.—As the cage commences to rise, we have the full weight of the cage and contents, plus the full length of the rope, as a dead load. Also a further load is placed on the rope to produce the upward acceleration of the moving load. Let W = total dead load at any instant, a = acceleration at any instant, and L = total load on the rope instant. Then $L = W + (Wa \div 32{\cdot}2)$.

The solution of the equation will give the load on the rope when the values of W and a are substituted. As the length of the rope is decreasing, W will decrease; and if the acceleration can be regarded as uniform, then the load on the rope will decrease as the cage ascends.

On the application of the brakes, there will be a retardation. If f equal the retardation, then the load on the rope at any instant is given by the equation $L = W - (Wf \div 32{\cdot}2)$, where W is the weight at the particular instant. During the period of braking the engine in the ascent a person riding the cage can usually feel a jumping action. This will have the effect of putting a jumping load on the rope.

Load due to Accelerating the Winding-pulley.—As the pulley rim acts as a carriage for the rope, it will have an acceleration in the same periods of the wind similar to the rope.

Let I = moment of inertia of a pulley, θ = angular acceleration of pulley, and T = twisting moment to produce the acceleration. Then $T = I\theta$.

Let R = radius of centre of rope to centre of pulley, and P = pull in the rope necessary to produce the above twisting moment. Then $T = PR$. Hence $PR = I\theta$; and, therefore, $P = (I\theta \div R)$.

From the latter equation we thus obtain the additional pull required in the rope merely to accelerate the winding-pulley. The latter load is always a positive one, and must be added to the load from other causes in order to arrive at the total load on the rope. Owing to the large mass of the pulleys, this load will be considerable, especially during the application of the brakes when the ropes are on the swinging movement. During this period of the wind, if a distant view of the headgear be taken, the fluctuations in the angular speed of the pulleys will be observed.

Stress in Rope due to Radial Acceleration in Passing round Pulley.—It can easily be shown that a tension is induced into the rope merely because it has a rotary motion with the pulley. In amount it is given by the equation $F = 12WV^2 \div G$; where F = tension in cross-section of rope, W = weight of rope per inch length, V = speed in feet per second, and $G = 32{\cdot}2$.

Figs. 1 and 2 show that the rope has a radial acceleration in passing round the pulley. Let a point in the rope be at P at a certain instant; then let it be at Q at an instant later; and let dt equal this increment of time between these instants. The direction of the velocity of the point has changed from along the tangent at P to along the tangent at Q. Let V = velocity of the point. Then ST (Fig. 2) represents the change in velocity, which is equal to $Vd\theta$. Hence the radial acceleration =

$$\frac{Vd\theta}{dt} = \frac{V^2}{R}\text{; where } R = \text{radius of pulley.}$$

The stress induced into the rope by this acceleration may easily be 1,000 pounds.

Proof of Statement.—Let w = weight of rope per inch length; then $12wds$ = weight of element of rope. Its centrifugal force = $\frac{12wds}{g} \times \frac{V^2}{r}$.

$$e.g.— \quad \frac{12wds}{g} \times \frac{V^2 d\theta}{ds} = \frac{12w}{g} \times V^2 d\theta.$$

Let T = tension in rope due to this centrifugal force. Then $Td\theta$ =

$$\frac{12w}{g} V^2 d\theta \text{; that is, } T = \frac{12w.V.^2}{g}.$$

Tension in Rope due to Friction in Bearing of the Winding-pulley.—Since the bearing of the winding-pulley takes up the total thrust due to the pulls on both sides of the pulley, there will be a lot of work done here. Let P = pull in rope due to this friction, u = coefficient of friction, a = radius of pulley-shaft, and R = radius of pulley. Then $P = uDa \div R$, where D = thrust on bearing.

Description of Apparatus to Obtain a Graphic Record of the Stresses on the Winding-rope during the Process of Winding.—As previously stated, I have considered many different ways of obtaining a method that will give the most accurate copy of the stresses in the winding-rope. For example, I have thought of putting a recorder in the cage, or of attaching a recorder between the cage and the rope, etc.; but have come to the conclusion that the best result will be obtained by putting a fitting in the headgear. In coming to this opinion, I have been guided by the fact that not only is the maximum stress required, but also the whole variation in stress

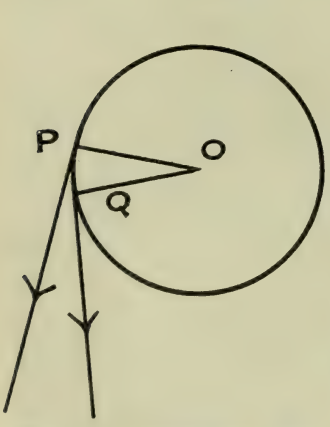


Fig. 1.—Illustrating the Radial Acceleration of the Rope in Passing round the Winding-pulley

Fig. 2.—Illustrating the Radial Acceleration of the Rope in Passing round the Winding-pulley.

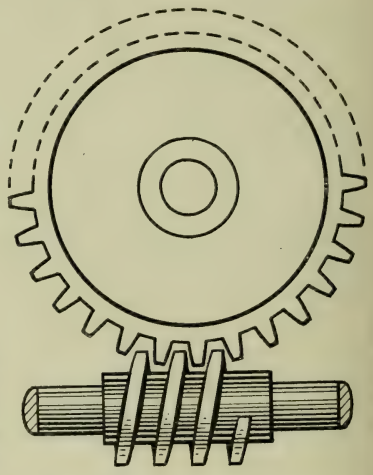


Fig. 3.—Worm-sleeve Keyed to Shaft of Winding-pulley.

during a complete wind and the definite points in the wind where these stresses occur. What I have in mind is really a dimensioned picture of the whole range of stresses, that will also indicate at what position in the wind each stress is recorded.

Fig. 3 shows a worm-sleeve keyed on to a shaft to which the winding-pulley is fixed; therefore whilst the pulley makes a complete revolution, the worm will advance the wheel one tooth. The wheel will have a sufficient number of teeth so that it will not make a complete revolution while the cages make a complete journey.

Securely fastened to the above wheel will be a light cylinder 15 inches in diameter, which will be the indicator-drum. Round the cylinder will be fastened the indicator-card. It will be observed that by having the drum 15 inches in diameter a chart over a yard long can be obtained.

As the variation of the stresses can be more readily seen by having them recorded on a big scale of travel, by varying the diameter of the drum it is possible to have as long a chart as desired. From experiments

and observations I have made, it would seem that the stress-chart produced would be something like the illustrated diagrams shown in Figs. 4 and 5. In order to show the vibration up clearly, it is necessary to have a fairly long diagram. The depth of the curve represents the load on the rope.

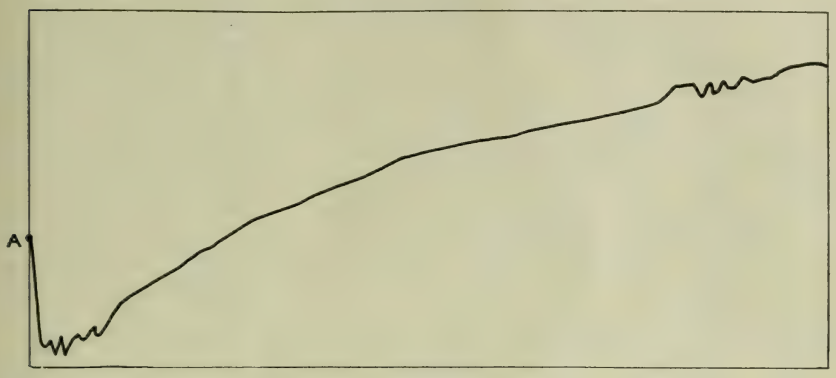


FIG. 4.—STRESS CHART OF ASCENDING CAGE, IN WHICH *A* REPRESENTS THE DEAD LOAD AT THE BOTTOM OF THE SHAFT, WHILST THE TENSION ON THE ROPE IS REPRESENTED BY THE DEPTH OF THE DIAGRAM.

The bearings of the winding-pulleys will be supported on springs which have been tested and graduated for deflection, and the bearings may be constrained to move vertically. The toothed wheel, with the indicator attached, will be carried on the bearing, so that whatever deflection there may occur in the bearing will also be shown on the

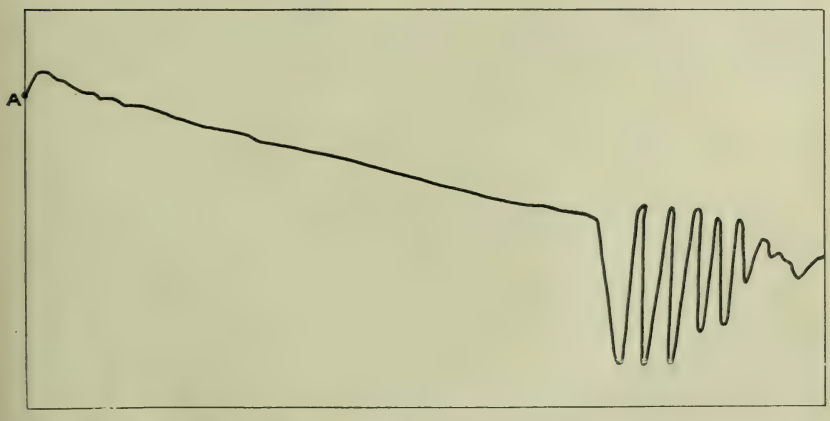


FIG. 5.—STRESS CHART OF DESCENDING CAGE, IN WHICH *A* REPRESENTS THE DEAD LOAD AT THE TOP OF THE SHAFT, WHILST THE TENSION ON THE ROPE IS REPRESENTED BY THE DEPTH OF THE DIAGRAM.

indicator-card. The indicator-card will move past a pointer at a fixed height, so that the deflection of the bearing will be marked on the card.

After making allowance for the weight of the pulley, the deflection of the indicator will be proportional to the resultant of the pulls in the rope on the two sides of the pulley. Let θ = angle between the rope and

the vertical, as shown in Fig. 6. Let P = pull in rope. Then R (Fig. 7) will represent the resultant. By calculation $R = \sqrt{2P^2 + 2P^2 \times \text{cosine } \theta}$.

FIG. 6.

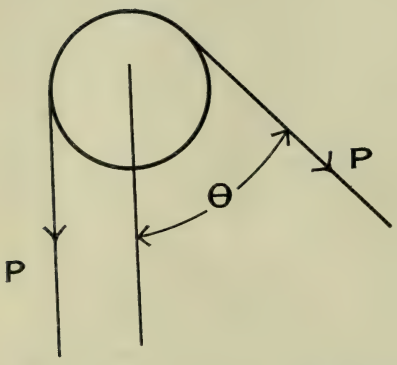
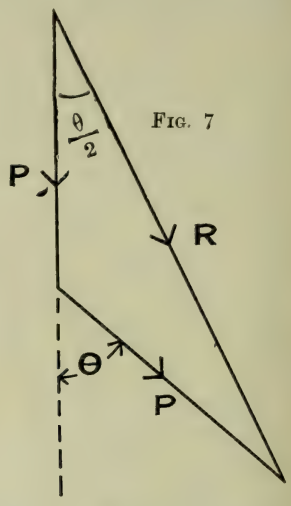


FIG. 7



FIGS. 6 AND 7.—ILLUSTRATING HOW TO FIND THE RESULTANT DOWNWARD PULL ON THE BEARINGS OF THE PULLEY.

Let D = deflection on the spring. Then D will vary as $(\sqrt{2P^2 + 2P^2 \cos \theta})$. It will be noticed that I have assumed, in order to get out the latter equation, the pulls on the two sides of the pulley to be the same, which is the case when the cages are at rest. A suitable calculation could be made to give the excess of the pull on one side over the other at other instants. The pulls on the two sides of the pulley will always be different when the cages are in motion, but a similar calculation can be made in any case. From the latter we find that—

$$P \text{ will vary as } \frac{D}{\left(\sqrt{2 + 2 \cos \theta}\right)}.$$

Hence we get an equation : $P = kD$, where k is a constant. Thus from this equation it will be seen that a graduated card can be put round the indicator-drum and the pull in the rope obtained directly from the card.

It will be observed that my endeavour is to obtain the information from as direct a source as possible, for I feel that when we can get at the source—although at a little expense—we should do so, as the knowledge obtained therefrom is true and can be relied upon. Knowledge obtained from models of apparatus, etc., is very often untrustworthy, and does not represent actual facts obtained in practice. Incidentally, the experiment described in this paper would give some additional information to that upon which head-gearing is designed. Also, a direct knowledge of the effect that the use of a conical drum has on the tension in the rope can be obtained. This would also illustrate the effect of using a balance-rope. It is with the hope of having secured a method of obtaining the true tension in the winding-rope, at any point in the wind, that I submit this paper to mining engineers.

Mr. H. M. Morgans (London): I am surprised to hear that an acceleration so high as 32·2 feet per second per second is obtainable in winding. In any case, where a sagging rope has been noticed behind a downgoing cage I would expect that no cage was coming up at the same time.

In discussing the stress in the rope, windage should be taken into account in addition to the factors mentioned by Mr. Stoney.

The author proposes to place his stress-recording apparatus under the bearings of the sheave-wheel shaft, but I would suggest that the sheave-wheel with its shaft and bearings might be suspended from two points, in which case standard dynamometers might be used. In developing the formula for the stress at the sheave-wheel, the author assumes that the stress in the sloping portion of the rope between sheave-wheel and drum is equal to the stress in the vertical portion of the rope, but this is not true when the rope is running. The work necessary for bending the rope and for accelerating the pulley increases the stress in the sloping portion of the rope.

Mr. L. Ridsdale (Streetly): Is it proposed that the apparatus should stay in position during ordinary winding of coal or men, or is it meant to be put in only for the purpose of a test?

Mr. J. Stoney (Smethwick): The 32·2 feet per second, as set down in the paper for the acceleration, is assumed to be that in vacuum. There doubtless would be a slight amount of resistance due to windage, but corresponding to the large stresses due to other circumstances I did not think it worth while to take it into account. If, however, there was a slight difference, the instrument I have described would give the correct pull due to all causes. If the intrument is applied at the top, it will give the correct reading due to everything from the time when the rope starts, and so the windage would be taken into account.

Every cause of acceleration in the winding of the pulley will have to be taken into account, and the pull on one side of the pulley will be greater than the pull on the other side, according to whether there is a positive or a negative acceleration. Also, the friction in the pulley bearing will cause an excess of pull on one side of the pulley over the other side. The suspension of the rope in the way that has been suggested could be carried out; it is just a matter of design.

The statement in the paper that the bearing is supported on springs applies to suspension as well as support. The cages are at rest when I assume the pulls in the two sections of rope to be the same.

With regard to the question put by Mr. Ridsdale as to whether the apparatus is to stay in position during winding, the paper was written with the object of obtaining information on that and other points. There is no intention of putting the apparatus in the head-gear and of allowing it to remain there during the ordinary operation of coal-winding.

As I stated at the beginning of the paper, Mr. Hindley and I read a paper thirteen years ago before the Manchester Geological and Mining Society, and at that time it was considered that the information given in connexion with our new appliance for arresting the descent of cages in shafts was very useful. It is quite true that it was a good appliance. But I knew perfectly well myself that the information from certain points of view was defective. I have endeavoured in this paper to obtain information from first causes. When the matter was considered

at Manchester, the members had before them the application of an indicator something like the one I have described, except that it was placed inside the cage. I knew, however, that it was not quite accurate, although it was a very good approximation to accuracy. We made actual practical tests, but it would be a big experiment to have one fixed in the headgear so as to determine the result of experience, and only a great body like The Institution of Mining Engineers could set to work and arrive at correct results.

THE NORTH STAFFORDSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING,

Held at the Central School of Science and Technology, Stoke-on-Trent, October 25th, 1921.

Mr. J. R. L. ALLOTT, President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen, having been previously nominated, were elected :—

Associate Member—

Mr. H. C. W. Roberts, The Avenue, Kidsgrove, Stoke-on-Trent.

Associate—

Mr. Arthur Moores, 64, King Street, Fenton, Stoke-on-Trent.

Transfers from Student to Associate—

Mr. R. G. Jenkinson, 29, Keele Road, Newcastle, Staffs.

Mr. L. W. Rogers, Sideway Farm, Stoke-on-Trent.

Mr. E. H. Vallis, Myrtle Cottage, Kidsgrove, Stoke-on-Trent.

THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,

HELD IN THE WOOD MEMORIAL HALL, NEWCASTLE-UPON-TYNE, OCTOBER 8TH, 1921.

Mr. C. C. LEACH, PRESIDENT, IN THE CHAIR.

DEATH OF SIR WILLIAM GARFORTH, LL.D.

The PRESIDENT: Prior to the ordinary business of the meeting, I wish to allude to the death of Sir William Garforth, which sad event has occurred since we last met. He was one of the great mining engineers in this country, and I am quite sure that you will wish to pass a vote of sympathy with his widow and family in the loss that they have sustained.

One of the greatest achievements brought about in mining was his recognition, so far as explosions are concerned, of the danger of the presence of coal-dust in mines and his introduction of stone-dusting in order to render our pits safer. Sir William was certainly one of the most interesting personalities in the Mining Institutes of this country, and he was largely instrumental in obtaining a Charter for The Institution of Mining Engineers. It is not too much to say that anyone who goes down the pits ought to love his memory. I ask you to pass this vote in the usual way.

The resolution of sympathy was passed by the members rising in their seats.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated:—

HONORARY MEMBERS—

Dr. PETER PHILLIPS BEDSON, Professor of Chemistry, Colwyn, Victoria Avenue, Sanderstead, Croydon.

Dr. JOHN SMITH FLETT, Director of Geological Survey and Museum, 28, Jermyn Street, London, S.W. 1.

MEMBERS—

Mr. JOHN HARVEY DAVIES, Granite Quarry Manager, "Ravencragg," Braithwaite, Keswick.

Prof. GEORGE HICKLING, Professor of Geology, Armstrong College, Newcastle-upon-Tyne.

Mr. JOHN ANGUS MACVICAR, Boring Engineer, Underwood, Bootle, Bootle Station, Cumberland.

Mr. ROBERT DOBSON OSWALD, Colliery Mechanical Engineer, Blaydon Burn, Blaydon-upon-Tyne, Co. Durham.

Mr. SAMUEL PLATTEN, Assistant Colliery Manager, 122, Argyle Street, Hebburn, Co. Durham.

ASSOCIATE—

Mr. REGINALD PEACOCK SMITH, Deputy Overman, 268, Milburn Road, Ashington, Northumberland.

PRESIDENTIAL ADDRESS.

By CHARLES CATTERALL LEACH.

My predecessors have covered so much ground in their Inaugural Addresses that it becomes progressively difficult to find any new subject for consideration or discussion. I propose, therefore, instead of attempting to break new ground, to draw attention to some of the achievements of our own Institute in the past, although it is not possible to do justice to them in a short paper; but I will try to show some of the things that it has accomplished or to which it has called attention.

The North of England Institute of Mining and Mechanical Engineers is the oldest and the mother of all the Mining Institutes. On June 23rd, 1852, this Institute was brought into being in consequence of a discussion which took place amongst Messrs. T. E. Forster, Matthias Dunn, T. C. Maynard, G. B. Forster, G. Elliot, and a few others, immediately after the inquest on the Seaton Colliery explosion.*

It is worth putting on record that the meeting took place in a public-house in Seaton. The various viewers and other authorities who attended the inquest were assembled and were debating the causes and means of preventing these disasters, when it was proposed by T. E. Forster and seconded by George Elliot that the advantages they were then deriving from the professional arguments and discussions should be extended to the rest of the coal-trade, and thus the present Institute was established shortly afterwards.

On July 3rd, 1852, a meeting of owners, viewers, and others interested in collieries decided to meet at fixed periods to discuss methods of ventilation, the winning and working of collieries, the prevention of accidents, and other matters.†

The first meeting of the newly-formed society was held on August 21st, 1852, in the Coal Trade Office, Newcastle-upon-Tyne. In those days it was most difficult to know what was being done in other districts, and the Institute speedily became the means of disseminating valuable information through its members coming together and by publishing the proceedings of its meetings, which were sent to all its members at home and abroad, and also by exchanging its *Transactions* with those of other Institutes and learned bodies.

In 1876 a Royal Charter was granted to the Institute.‡

In 1868 George Elliot suggested that we should endeavour to amalgamate with other Mining Institutes in the country,§ so as to ensure a more general recognition of the importance of our calling; but it was not until 1889 that the federation of the majority of the Mining Institutes of the country was brought about.‖

The headquarters of the Federated Institution of Mining Engineers were in Newcastle at the offices of our Institute, and the late M. Walton

* *Trans. N. E. Inst.*, 1868-1869, vol. xviii., page 20.
† *Ibid.*, 1852-1853, vol. i. (second edition), page 1.
‡ *Ibid.*, 1876-1877, vol. xxvi., page xlix.
§ *Ibid.*, 1868-1869, vol. xviii., page 29.
‖ *Trans. Inst. M. E.*, 1889-1890, vol. i., pages viii.-x.

Brown acted as Secretary. Within two years of his death in 1907, the Institution decided at its Twentieth Annual General Meeting in 1909 to move its headquarters to London. At this meeting, held in Newcastle-upon-Tyne, a unanimous vote of thanks was accorded to The North of England Institute of Mining and Mechanical Engineers for their kindness in having until then provided office accommodation, free of rent, rates, and taxes, for the staff of the Federated Institution.

In 1915 The Institution of Mining Engineers, as it was then called, obtained a Royal Charter, which recognized it as a corporate body, whilst each Institute retained its individuality.*

This year we have gone one step further, and have joined forces with The Institution of Mining and Metallurgy, but still maintain our separate identity. This step will, it is believed, be of great advantage to our common interests.

It is interesting to note the importance and variety of subjects dealt with in our *Transactions* during the past 69 years.

Ventilation.—In 1807 Buddle's air-pump at Hebburn Colliery (described in the *Transactions*) had a wooden piston made of 3-inch planks, 5 feet by 5 feet square, with an 8-foot stroke, working at 20 strokes per minute and drawing from 5,000 to 6,000 cubic feet of air per minute. In 1813 he used an air-pump for ventilating, which produced 8,000 cubic feet (or 778 hogsheads) of air per minute.†

In 1848 Seaton Delaval used twenty-five steam-jets, each $\frac{3}{8}$ inch in diameter, for ventilating.‡ In 1854 J. J. Atkinson read a great many papers on "The Theory of the Ventilation of Mines," and stated that "a correct and perfect theory will always be found to agree with the results of practice."§ He drew attention to the laws which govern ventilation, the effect of rise and dip workings on the quantity of air, and the effect of rubbing surfaces and temperatures, and showed that in order to double the quantity of air eight times the power was required, and to treble it twenty-seven times the power; so that it was absolutely necessary to split the air to obtain large volumes. Nicholas Wood said that J. J. Atkinson's paper "contained the entire theoretical exposition of the ventilation of coal mines, than which nothing could be of more interest to the society."‖

A. L. Steavenson and W. Cochrane made most valuable experiments on various types of fans and on their useful effect. J. A. Longridge stated that, "the amount of fuel consumed, is more than sufficient to produce, by the ordinary furnace, the whole effect obtained by the more expensive and more dangerous apparatus of steam boilers."¶ Apparently these were underground boilers for steam-jets. On the other hand, in 1853 A. L. Steavenson said, "I am prepared to prove the application of steam to pump air is more effective in ventilation than the steam jet." The steam jet has been superseded, thus justifying both views.

The next stage in the development of ventilation was the battle of the fans between those which were centrifugal and those which displaced or pumped the air. Amongst the former may be named the Capell fan, which succeeded in obtaining extremely high water-gauges, up to as much as 18 inches on the Continent.

* *Trans. Inst. M. E.*, 1915-1916, vol. l., page xii.
† *Trans. N. E. Inst.*, 1865-1866, vol. xv., page 221.
‡ *Ibid.*, 1852-1853, vol. i. (second edition), page 35.
§ *Ibid.*, 1854-1855, vol. iii., page 74.
‖ *Ibid.*, page 236.
¶ *Ibid.*, 1852-1853, vol. i. (second edition), page 59.

In 1900 a most exhaustive joint report of a Committee of our Institute and of the Midland Institute of Mining, Civil, and Mechanical Engineers, edited by the late M. Walton Brown, contained the fullest particulars of the actual performances of mechanical ventilators.

Haulage.—In 1852 Hetton Colliery had 40 miles of single underground railway.* In 1855 Nicholas Wood read a paper "On the Conveyance of Coals Underground in Coal Mines,"† and showed by experiments that the friction of tubs was 1/108th of the weight, and of railway-wagons 1/240th; also that inclined planes self-acted at 1 in 30.

At Killingworth Pit, before 1824, a first haulage-engine, placed near the pit-bottom, pumped water 20 fathoms up a staple, and drew coals to the pit-bottom a distance of 500 yards from the dip.‡ A second engine was placed in-bye at the point from which the first engine dragged the coals, and this hauled for another 500 yards from an increased depth of 20 fathoms; and lastly a third engine was erected at 1,000 yards from the pit-bottom and at a level of about 40 fathoms below it, and dragged the coals a further 500 yards at an increased depth of 30 fathoms, or a total of 1,500 yards, from and 80 fathoms below the pit-bottom. The boilers were set at the stations where the engines were placed, the smoke being conveyed by flues or drifts for that purpose to the upcast shaft.

Water was likewise pumped from the extreme distance, and from a depth of 80 fathoms below the pit-bottom, by a system of sliding wooden spear-rods and pumps laid down the drift.

There was at Killingworth a common beam high-pressure engine on the surface for haulage; the rope was taken down the pit 175 fathoms and 800 yards in-bye. The cylinder was 25 inches in diameter, had a 5-foot stroke, with a second motion of 4 feet to 8 feet 4 inches, and a drum 9 feet in diameter. Steam was raised by two boilers, each 6 feet 6 inches in diameter and 23 feet long; the plane dipped 1 in 5·485. This seems to have been a usual type of engine at that time.§

The Elemore engine at Hetton Colliery had two 12-inch cylinders with 2-foot stroke, geared $2\frac{1}{2}$ to $4\frac{1}{2}$; the wheel on the roll was 4 feet 6 inches in diameter. There was one boiler, 5 feet 4 inches in diameter and 31 feet long, and it was placed underground.‖

In 1867 a report was made on five systems of haulage and their initial and working costs.¶

J. T. Cackett and B. N. McLaren presented a large plan of the underground haulages set up and worked at the Royal Jubilee Exhibition held at Newcastle in 1887, and this still hangs in our Institute.**

In the place of the old sleds and barrows on plank-ways, iron rails and chaired ways were adopted for the engine-roads; flat-bottomed rails and fishplates were a later improvement.

Papers were read on endless chain and endless ropeways, with single tubs and in sets.

T. M. Jobling used steam locomotives in the pit;†† and mechanical putters (air locomotives) were tried, but both were found too cumbersome. Storage-battery locomotives are now being experimented with.

* *Trans. N. E. Inst.*, 1852-1853, vol. i. (second edition), page 27.
† *Ibid.*, 1854-1855, vol. iii., page 239.
‡ *Ibid.*, page 275.
§ *Ibid.*, page 291.
‖ *Ibid.*, page 294.
¶ *Ibid.*, 1877-1878, vol. xvii., appendix i.
** *Ibid.*, 1887-1888, vol. xxxvii., page 85.
†† *Ibid.*, 1862-1863, vol. xii., page 176.

Sinking.—It is interesting to look at what Edward Potter did in sinking Murton Colliery.* Sinking began in 1839, and in April, 1843, the Hutton Seam was reached. The pit was 14 feet in diameter (finished), and at 90 fathoms a quicksand 34 feet thick was met with: the shaft here was widened out to a diameter of 28 feet, and wooden piles were used to get through the sand. A feeder of 9,306 gallons of water per minute was pumped by six 19-inch sets and three 16-inch sets of pumps, and the nine engines had a total of 1,840 horsepower. Steam was obtained from thirty-nine boilers. The pit was 18 feet 3 inches in diameter, and there were nine sinkers in the pit-bottom at a time. There were five pairs of main crabs, nine pairs of ground crabs, three cradle-crabs, and three gins, all worked by horses. The pit was sunk to a depth of 248 fathoms at an average rate of 2 fathoms 1 foot 1 inch per week, and took about four years to sink. This certainly was a marvellous performance, and the plans of the arrangements are well worth looking at.

Afterwards at the Dudley Pit, Northumberland, Edward Potter designed and used a steam-driven geared crab, as the ground crabs lost so much time in flitting the rope.†

At Whitburn, where the water feeder was 12,000 gallons per minute, it was decided to sink by the Kind-Chaudron system, and to bore out the pit the full diameter through the limestone.‡

Freezing water-bearing strata was first accomplished successfully in this country at Washington by Mark Ford in 1902; this process and cementation are now resorted to. Electric centrifugal pumps and electric light in the pit-bottom are great improvements.

Pits are being sunk by the aid of the permanent winding-engines, resulting in great economy of coal, and compressed-air drills are generally used.

In the Blackhall sinking 14,300 gallons of water per minute were pumped, and seven years were required to sink the pit.

In 1906 Bentley Colliery was sunk through 50 feet of quicksand, feathered-and-grooved steel piles being used.

Winding.—In 1831 coals were drawn from Townely, Chopwell, Throckley, and other pits by means of gins and horses, and at Brandon, Co. Durham, "the gin was worked by a bull in harness attended by a female."

An account by T. Y. Hall of South Hetton states that in 1833 in a pit 182 fathoms deep a 60-horsepower engine drew 110 or 113 scores of $6\frac{1}{2}$ tons, equal to 700 tons per day, this being "the greatest quantity that had been produced at any one pit, either at this depth or any less depth, either before that time or since" (up to 1852).§

Water-wheels were also used.

Single vertical-cylinder engines used to be common in this district, but about 1870 horizontal cylinders came to stay.

Winding-engines are steam-eaters, but John Daglish adopted an automatic variable cut-off gear controlled by a governor; and Corliss drop-valve gears and steam-jackets saved a large amount of steam, and compound winders made for further economy.

Enormous scroll-drums were in fashion for some time, but their

* *Trans. N. E. Inst.*, 1856-1857, vol. v., page 43.

† *Ibid.*, page 56.

‡ *Ibid.*, 1880-1881, vol. xxx., page 45.

§ *Ibid.*, 1853-1854, vol. ii. (second edition), page 197.

terrific weights were against economy, and now a scroll to help the engine to get into speed and a flat surface for the rest of the wind is considered the most economical form of drum.

The winders at Bentley Colliery are cross-compound, with a high-pressure cylinder 35 inches in diameter, low-pressure cylinders 85 inches in diameter and 6-foot stroke, the steam-pressure at the four boilers (9½ feet by 30 feet long) being 160 pounds per square inch, with a drum 9 feet 8 inches in diameter, rising to 19 feet on the flat part. The engine has wound 4,543 tons in 15 hours actual winding from one of the shafts. The heapstead and the legs at the upcast are of ferro-concrete.

The utilization of exhaust-steam in turbines has revolutionized the power for driving dynamos, and has lifted the steam winder from being so wasteful of steam, as its huge exhausts yield about as much power as is exerted by the winder, thus halving its previous cost of steam.

Many electric winders have been working satisfactorily for some years.

Safety Cages and Hooks.—A Committee was appointed to investigate a number of safety cages, and though several of them had come into action "successfully," several gentlemen seemed to think that the risk incurred with the grips would be greater than the benefit they were likely to confer on the workmen, especially in regard to deep pits where great speed was required, and it was contended that grips and guides could not be kept in order.* This opinion still holds good to-day.

Detaching-hooks were approved, and were generally adopted long before they were made compulsory.

Cages with wooden guides were universal until about fifty years ago, when steel rail-guides down one side of each cage were introduced; this did away with the reversing guides, and left the middle of the shaft clear of obstructions.

Rope-guides are put into deep pits which are large enough in diameter to allow for the swing of the ropes, which is lessened by their being unevenly weighted.

Steam.—The old haystack and wagon boilers of about 2 pounds pressure and atmospheric engines have been superseded, first by egg-ended boilers of small diameter and later by Cornish and Lancashire boilers of about 7 feet diameter, with pressures of 30 to 40 pounds per square inch; these are now built up to 10 feet in diameter by 30 feet long, and work up to 180 pounds. Water-tube boilers are also used, especially for utilizing the waste-heat of the coke-ovens. Doing away with the egg-ended boiler reduced the consumption of coal by one-half.

By superheating steam about 12½ per cent. is saved, whilst economizers and covering the boilers and pipes effect still further economies. Mechanical stoking, chain-grate furnaces, and forced draught to burn refuse coal are all in use.

Coal-cutting.—In the Earl of Balcarres and Crawford's pit a coal-cutter having two 3½-inch cylinders, worked by compressed air up to 6 horsepower, was employed to drive a place for a distance of 200 yards. This place was cut 5 yards wide, and the height of the seam was 4½ feet. The machine was 3 feet long, 2 feet wide, and 2 feet high, and travelled on rails, or on the thill of the seam on castors. The cutters moved forward by their own power, while the machine remained fixed.† Another machine was a pick coal-cutter, with an arm 3 feet 4 inches in

* *Trans. N. E. Inst.*, 1869-1870, vol. xix., appendix i.

† *Ibid.*, 1854-1855, vol. iii., appendix xii.

length, which was working 1,000 yards away from the air-compressor. Many other machines have been reported on.

There are great difficulties in making coal-cutting a practical operation. We now have bar, disc, and chain machines, and also percussive air-machines, and thin seams which could not be got by hand labour are being worked by these. Shaker, scraper, and belt-conveyors along the face deliver the coals into tubs at the gate-ends, and where any of them can be employed replace putters. Their introduction was largely due to the enterprise of W. C. Blackett, who wrote a valuable paper on the subject in 1905.*

In 1903 a Committee was formed to report upon Mechanical Coal-cutting, and issued its report of over one hundred pages in due course, giving methods of payment and costs of working.

Air-compressing machinery has been fully investigated, and high-speed compressors are extensively employed; turbo-compressors are used when large volumes of air are required.

Methods of Working.—Many papers have been written on the bord-and-pillar, longwall, double-stall, and other systems, and also on the behaviour of the roof and thill, and the methods of controlling them.

Hydraulic stowing has been discussed and its prohibitive cost, except in very exceptional circumstances, pointed out. Systematic timbering was necessary for conveyor-faces, and is to a certain extent a safeguard. The tapering of wooden props at one end reduces the loss by breakage. Some viewers advocate steel props.

Creosoted timber, which absolutely prevents decay, has been used for many years with the most economical results under conditions where uncreosoted timber decays quickly.

Coal-dust.—In 1844 Faraday reported coal-dust as an adjunct in the Haswell explosion, but the subject did not attract much notice until 1876. Prof. A. S. Herschel said "that finely divided dust was capable of transmitting flame through a dust-charged atmosphere they knew from the disastrous results in flour-mills; and to what extent the action of coal may be similar to that of flour and of some other dusts was exactly one of the points which required examination."†

Prof. A. Freire-Marreco and D. P. Morrison stated that Galloway's experiments showed that 1 to 1½ per cent. of gas to air will not explode, and that coal-dust in air will not explode—at any rate, in contact with a naked light—but that both together will.‡ Henry Hall exploded dust with great violence in an old pit-shaft in 1890. One reason, I think, why the general opinion was for so long against the explosibility of coal-dust was that if it were explosive, explosions would have been of constant occurrence, seeing that hundreds of thousands of shots were fired every day; fortunately, it requires a great many conditions to be exactly right in order to get an explosion of dust.

Later a strong feeling evolved that dust was explosive, or, at any rate, that it carried on an explosion. The Institute appointed a Flameless Explosive Committee in 1888, and reorganized it later to test the claim of the makers that the temperature of the gaseous products was so low that they were incapable of igniting firedamp or coal-dust.

A boiler tube 3 feet in diameter and 101 feet long, with twenty-three windows along one side, was set up at Hebburn, and pit-gas piped to it

* "The Conveyor System for Filling at the Coal-face, as Practised in Great Britain and America," *Trans. Inst. M. E.*, 1904-1905, vol. xxix., pages 449.

† *Trans. Inst. N. E.*, 1876-1877, vol. xxvi., page 105.

‡ *Ibid.*, 1878-1879, vol. xxviii., page 85

from underground; observers noted what occurred by looking through the windows. The results pointed conclusively to the unreliability of all explosives. Later, as the gas was not procurable, these experiments were brought to a conclusion, and a report of 130 pages on the experiments, edited by A. C. Kayll, was published. The late Sir William Garforth (whose loss we all deplore) found that the explosion at Altofts Colliery travelled only along the roads on which the coal was hauled, and not in the returns travelled by the men and horses where there was an abundance of stone-dust kicked up, and this led him to stone-dust his haulage-roads.

He then set up a long gallery, formed of old boilers, at Normanton, and made a series of further experiments; but some of the explosions were so violent that they broke the windows in the houses, and at last burst the gallery, hurling pieces right over the Midland Railway lines, a considerable distance away.

After this the Government set up a station at Eskmeals under Dr. Wheeler, by whom various tests were conducted and experiments made on this important subject.

Watering the roads in order to damp the dust fails as a remedy, because the water dries up so quickly, and because many roads will not stand it, and the use of salt and chemicals is out of the question. Stone-dusting is at present the one safe cure, and I think that this is one of the greatest modern discoveries, for his share in which the late Sir William Garforth got a well-deserved knighthood. "The fact," said the late J. W. Fryar, "that the Nottinghamshire Coalfield had naturally an average of about 43 per cent. of stone-dust in the total dust in the mines, and had not had a dust explosion in its history, was a very good basis to work upon in legislating for the safety of the English coalfields."*

Safety-lamps.—We have it recorded that in 1760 Spedding invented the steel mill; in 1813 came Dr. Clanney's lamp; and in 1815 George Stephenson's and Davy's lamps were invented.

A great improvement was the bonnet to prevent the flames from being blown through the gauze and thus igniting gas. Committees investigated gauzes, lamps, and their behaviour. Lamps for detecting minute percentages of gas were tested, and double gauzes, glasses, assembling, etc., all received attention. Portable electric safety-lamps are being used, but they cannot yet detect gas.

Blowers of Gas.—Many reports on blowers are to be found in our *Transactions*. At Pelton Colliery a blower after a shot went off burnt furiously on the surface of the water with a great noise, the gas alternately returning under the brow and coming out in a mass of flame which filled the drift. It was thought at first that the motion of the water, which was very great, lashing up against the roof would extinguish it, but after waiting for some time and finding that this did not take place, and that the gas continued to advance in a solid flame full 40 yards beyond the brow, it was decided to try and knock it out with gunpowder. About 12 pounds were employed, with a sufficient length of fuse to enable the man that lighted it to escape, and no sooner had he done so than the explosion by its concussion extinguished the burning gas.† There was plenty of courage in the old days.

In 1868 George Elliot drew attention to "the exudation of highly-compressed gas from the strata. This was sensibly cooler to the touch,

* *Trans. Inst. M. E.*, 1914-1915, vol. xlix., page 777.

† *Trans. Inst. N. E.*, 1854-55, vol. iii., page 36.

just as is the air which escapes from the high-pressure pneumatic engines ''*; so he realized that the gas in the strata was under considerable pressure.

In 1876 the New Oaks outburst of 10,000 cubic feet per minute produced returns so loaded with gas that lamps at the bottom of the upcast were extinguished, although 140,000 cubic feet of air per minute were travelling through the workings.† S. C. Crone observed that '' gas did not always exude from the coal itself, but from backs or partings in the stone or the surrounding strata,'' and that a large blower of gas at Killingworth '' burned for a great number of years with as much vigour as formerly.'' Wallsend gas, piped to the surface, did the same. At Boldon the pressure of gas at the back of a hole bored 32 feet into the solid coal was 461 pounds per square inch.‡

Rescue-apparatus.—T. Y. Hall read a paper on '' Penetrating Dangerous Gases '' by means of rescue-apparatus.§ Pipes were to be laid in the mine, supplied with fresh air with stop-cocks every 50 yards, and the rescuer had to wear an airtight suit with an outlet and an inlet tube to connect to these pipes; his picture looked like a diver.

Fleuss's apparatus was self-contained.‖ In 1914 Dr. J. S. Haldane made numerous experiments on many of these appliances at the Doncaster Coal Owners' Laboratory, and pointed out their defects, and the methods of using which required guarding against.

Screening and Washing.—At first coals were sold as they came out of the pit, and then they were screened over fixed sloping bars $\frac{3}{4}$ inch apart, and later over oval revolving bars fixed $\frac{3}{8}$ inch apart. Hicks's revolving screen separated the coals into best coal, nuts, and smudge, but gave no opportunity of picking out the stones or dirt.¶ Then shaking screens and plate and bar belts to enable dirt to be picked out (worked by engine or motor power) came into use. Separation by leaving the small in the pit by filling by a fork instead of a shovel was practised at some collieries.

Many systems of washing coal, depending on the different specific gravities of coal and dirt, were introduced; some depended on air-blowing, and quite recently froth flotation has been proposed.

Coke.—This was first made by burning heaps of coal on the ground and afterwards in beehive coke-ovens, in which all the gases are wasted. About the year 1850 the gases from the ovens were used to heat the boilers, and about fifty years ago patent ovens came into use, so that the by-products were secured out of the volatile matter, as well as the waste-heat.

For many years patent coke was made by only those companies who had their own blast-furnaces, as it had not the silvery appearance of the beehive oven coke, and there was much prejudice against it.

Surveying.—Arthur Beanlands introduced a new method of connecting surface surveys to underground surveys by the transit theodolite, working to about 1 minute of a degree, which was correct enough for colliery plans and superior to any other method down a pit.** The

* *Trans. Inst. N. E.*, 1868-1869, vol. xviii., page 29.
† *Ibid.*, 1881-1882, vol. xxxi., page 11.
‡ *Ibid.*, 1882-1883, vol. xxxii., page 127.
§ *Ibid.*, 1853-1854, vol. ii. (second edition), page 85.
‖ *Ibid.*, 1881-1882, vol. xxxi., page 197.
¶ *Ibid.*, 1871-1872, vol. xxi., page 295.
** *Ibid.*, 1870-1871, vol. xx., page 85.

magnetic needle is difficult to read accurately and keeps varying and is attracted by rails and girders. Lines hung down a shaft are most difficult to keep from oscillating.

Education.—In 1854 Nicholas Wood proposed that a Mining College be founded in connexion with the Institute, and in the next year the coal-trade most favourably considered the question.* It was suggested that the Government should pass a Bill to force a payment of so much a ton to support the College; the President replied that this "had been hinted at, but it would require serious discussion before such a scheme could be proposed."†

The College (now Armstrong College) was opened in 1871 in rooms in the Coal Trade Offices, Newcastle-upon-Tyne, and it has been of great benefit to the industry; it has now buildings of its own, but requires more support than it receives, and I see by last Monday's paper that it had its jubilee this week, and at the same time shows a deficit on the year's working of nearly £16,000. It would be a calamity if its activities and usefulness were to be curtailed.

Geology.—Many very instructive papers have been read upon this and other districts, which suggested extensions of coal areas, and even new districts, as in Kent.

The Institute has set a very good example in collecting the information respecting the structure of the Northumberland and Durham Coalfields in its three volumes of Borings and Sinkings, and also in publishing the Report of its Committee on the Carboniferous Limestone Formation of the North of England.

The Institute has a most valuable Library of books on mining and associated subjects, plans, etc., in its Wood Memorial Hall. Visits to collieries and works enable members, who otherwise would not have the opportunity, to inspect them. The Institute at one time possessed a very valuable collection of safety-lamps, but these were destroyed in 1910 in a fire at the Brussels Exhibition, where they were on loan.

I trust that by the foregoing brief summary I have made it clear to you that an immense amount of research and study has been carried on by our Institute. It has led the way in nearly all the improvements for safety and comfort; it has investigated the causes of accidents and methods for their prevention; it has been a Welfare Institute all through its life of 69 years; and it ought to have been more consulted and its counsels more heeded before changes were made, some of which hamper improvements and are dangers in disguise, and do not lead to safety.

Examinations are too theoretical, and practical men who cannot pass them are often the best judges of work, and are better fitted to be officials than many who do pass. The official who can handle men is the man who keeps them safe. Again, why should a surveyor be kept from sitting for his examination until he is 21? Why have such restrictive rules, which are preventing the best type of man from taking up the profession of mining, owing to its being so tied up with red tape as to destroy individuality and retard progress?

This Institute has endeavoured always to get the greatest practical security for the workmen, and it may claim to have been successful, as the death-rate now is less than one-fifth of what it was sixty-nine years ago when the Institute was formed, and the pits are much more comfortable, both underground and on the surface.

* *Trans. Inst. N. E.*, 1854-1855, vol iii., page 56.
† *Ibid.*, page 243

Before closing, I should like fully to acknowledge the work accomplished by the six Mining Institutes federated with us, as well as that of the South Wales Institute of Engineers. Many of their members are members of our Institute, too; they also have problems in their districts which are often very complex, and it is a great advantage to all parties to know what each is doing.

Pits are extremely interesting, and members, especially the younger ones, by investigating matters which come their way, will find such investigations a help towards enjoying their work; they will also benefit the Institute by reading papers on the results of their observations.

We can claim that the Institute has not only accumulated a mass of most valuable information, but has also provided much food for thought. Those who have accomplished these things deserve the praise given in Wilson's *Pitman's Pay* to the inventor of " metal ways " :—

> " But heavy puttin's now forgotten,
> Sic as we had in former days,
> O'er holey thill and dyels a' splitting,
> Trams now a run on metal ways.
>
> God bless the man wi' peace and plenty,
> That first invented metal plates,
> Draw out his years to five times twenty,
> Then slide him through the heevenly gates."

Mr. John Simpson (Past-President): I have great pleasure in proposing a vote of thanks to the President for his most interesting Address. We are all greatly indebted to him for putting into so small a compass a review of what we have accomplished as an Institute, a record which I do not think has been sufficiently appreciated by the general public. Mr. Leach has touched upon practically every point of interest that could be mentioned, and I feel sure that we shall read his Address with care and interest in our leisure moments.

Mr. Philip Kirkup, Junr. (Chairman of the Students' Section): I am pleased to second the vote of thanks, and to express our appreciation of the way in which Mr. Leach has surveyed the ground. At the same time, I should like to take the opportunity of conveying to him our thanks for the encouragement that he has given to the younger members in his remarks to-day.

The vote of thanks was carried by acclamation.

The President: I thank you for your kind expression of appreciation of my Address. You must not think, however, that because we have done so much in the past that there is now nothing more to do. The more our knowledge extends, the more roads there are open for further investigation. If the younger men in our profession in particular could be left alone a little and given more leisure, I think that we should have still more interesting papers from them. One point that struck me when looking up the matter for my Address was the great pains that were taken by the early members in collecting exact information of all kinds, especially when taking out figures, some of which go even to the thousandth part of an inch. I am greatly obliged for your kind reception of my Address.

THE MIDLAND COUNTIES INSTITUTION OF ENGINEERS.

ANNUAL GENERAL MEETING,

Held at the University College, Nottingham, October 15th, 1921.

Major T. P. BARBER, D.S.O., President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen were duly elected :—

Members—

Mr. Norman Baster, Colliery Manager, 84, Nottingham Road, Sherwood Rise, Nottingham.

Mr. Frank Henry Lee, Mining Engineer, 63, Arthur Street, Derby.

Mr. G. C. H. Nasmyth, Colliery Manager, Tilford, Farnham.

Mr. Albert Edward Phipps, Civil and Mining Engineer, 2, Court Road, Bridgend.

Mr. Arthur Riley, Colliery Manager, 1, Lincoln Street, Tibshelf, Alfreton.

Associate Members—

Mr. Silas Bratley, Mine-rescue Instructor, Central Rescue-station, Ilkeston, Derbyshire.

Mr. John Munro Watson, Lecturer in Mining, University College, Nottingham.

Associate—

Mr. Thomas Henry Fleetwood Adams, Mining Engineer, Byron House, Low Moor Road, East Kirkby, Nottingham.

Students—

Mr. Francis Gilderoy Glossop, Assistant Mine Surveyor, 26, St. Mary's Gate, Chesterfield.

Mr. William Taylor, Student, c/o Mrs. Turney, Gorse Hill, Mapperley Plains, Nottingham.

Mr. Eric Colin Wright, Articled Pupil, Quarry Road, Somercotes, Alfreton.

Major T. P. Barber was unanimously re-elected President for the ensuing year.

ABSTRACT OF ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

The membership of the Institution shows a slight increase, and now stands at 340, as against 331 for the previous year.

The income-and-expenditure account calls for very little comment, and the only item which shows any appreciable change is that of the Call to The Institution of Mining Engineers, which has grown in accordance with the anticipations of twelve months ago. This item will during the current year be still further augmented, and hence the necessity for increasing the subscription of all classes of members. This increase has already been decided upon by all the Institutes comprising The Institution of Mining Engineers.

THE MIDLAND COUNTIES INSTITUTION OF ENGINEERS: ABSTRACT OF INCOME-AND-EXPENDITURE ACCOUNT FOR THE YEAR ENDED JULY 31ST, 1921.

EXPENDITURE.	£	s.	d.
To The Institution of Mining Engineers	393	7	0
,, Printing, stationery, exchanges, and excerpts ...	72	9	3
,, Postages, parcels, etc.	17	9	1
,, Expenses of meetings and reporting	9	14	6
,, Secretary's salary, use of office, auditors, and travelling expenses	170	9	4
,, Bank commission and sundries	1	7	1
,, Balance at bank	198	5	9
	£863	2	0

Investments:—

£750 5-per-cent. War Loan, 1929-1947.

£640 2½ ,, Midland Railway Debenture Stock.

£200 3½ ,, East India Railway Debenture Stock.

£500 4 ,, Funding Loan, 1960-1990.

INCOME	£	s.	d.
By Balance brought forward	157	1	1
,, Current subscriptions and entrance-fees	538	8	6
,, Arrears of subscriptions	48	1	0
,, Subscriptions paid in advance	33	16	0
,, Interest on investments and bank interest	71	13	11
,, Sale of *Transactions*	0	5	6
,, Return of income-tax	13	16	0
	£863	2	0

Three General Meetings have been held during the year, and three papers have been read. The meetings have been better attended than for the past few years, and the Council trusts that this improvement will continue.

Owing to the unsettled condition of the coal-trade both in 1920 and 1921, it was found impossible to arrange for the usual excursion meeting. It is hoped, however, that this is merely a postponement, and that with the expected occurrence of more normal conditions in 1922 this feature will be resumed.

Considerable additions have been made to the technical library at the University College, Nottingham, and the Council desires to remind members that they are entitled to obtain the loan of books therefrom, and that this Library comprises also the volumes belonging to the Institution. Members desiring to borrow books should apply to the Secretary of this Institution for the necessary ticket.

On the motion of the President, seconded by Mr. G. J. Binns, the Annual Report and Accounts were adopted.

ALTERATION OF RULES.

In accordance with notice given on February 12th, 1921, the President moved, and Mr. E. E. Bramall seconded, that the following alterations be made in the Rules :—

That Rules 33, 34, 35, 36, 37, and 38 be deleted, and the following substituted in their place :—

Rule 33. The annual subscription of each Member shall be £3 3s. 0d., with an entrance-fee in addition of £1 1s. 0d.

Rule 34. The annual subscription of each Associate Member shall be £3 3s. 0d., with an entrance-fee in addition of £1 1s. 0d.

Rule 35. The annual subscription of each Associate shall be £2 2s. 0d. No entrance-fee.

Rule 36. The annual subscription of each Student shall be 25s. No entrance-fee.

Rule 37. If any Associate or Student be elected a Member or Associate Member, 10s. 6d. shall be paid by him as transfer-fee. Each succeeding annual subscription shall be £3 3s. 0d.

Rule 38. Colliery companies, engineering firms, and institutions, if approved by the Council, may be elected Subscribing Members of the Institution for an annual subscription of £3 3s. 0d. They will not be entitled to vote on any question affecting the management of the Institution or on the election of members.

The alterations were unanimously agreed to.

PIT-SHAFTS.

By H. EUSTACE MITTON, M.Inst.C.E.

Introduction.—From 1900 to 1914 the development of the Midland Coalfield proceeded at a greater rate than at any time during the mining history of that district. The deeper seams of Derbyshire and Nottinghamshire were sunk to, and new collieries were opened up in Nottinghamshire and South Yorkshire for the winning of the Top Hard or Barnsley Seam. In 1914, however, development-work practically ceased, due to conditions arising from the war, and, with one or two exceptions, has not been resumed.

Owing to the activities of certain parties, the extension of the Top Hard Seam in the east of Nottinghamshire has been proved, and large areas of this seam and of other seams now await the time when conditions in the industry will permit of their being won.

The conditions for laying out a new colliery have altered entirely since 1914, owing to the increased cost of labour and material, the greater depth of sinking, and the difficulties encountered in connexion with the heavily-watered overlying measures.

The pit-shaft is the "neck of the bottle," and, owing to the high cost of labour and material to-day, the mining engineer must devote considerable attention to the question of the most economical size of shaft required for winning the contemplated area.

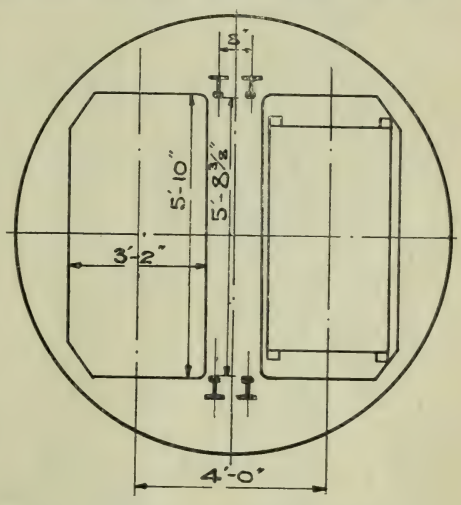


Fig. 1.—Position of Cages, Guides, etc., in Shaft 9 Feet in Diameter. Scale, 4 Feet to 1 Inch.

Coal-shafts in the Derbyshire and Nottinghamshire Coalfield vary from 9 to 22 feet in diameter. The cost of sinking increases very rapidly after a certain diameter has been reached, owing to the extra difficulties encountered in dealing with water and bad ground, and especially true is this in the case of the heavily-watered sandstone overlying the Coal-Measures in Nottinghamshire and South Yorkshire.

In laying out a new colliery the size of the shaft is determined by many considerations, amongst which the following are the principal:—

(1) The area to be won.
(2) The depth of the seam from the surface.
(3) The ventilation and cooling of the mine.
(4) The output.
(5) The minimum number of decks required to charge and discharge the cage with as little labour as possible.

(6) The space available for cables, pipes, etc., the clearance of the cages, and for the conductors.

(7) The minimum number of signals.

(8) The type of guides.

Good outputs are being obtained from shafts of small diameter, as the examples given in Table I. of what is being done at collieries under the writer's control will demonstrate.

Table I. shows the great advantage in having a shaft of sufficient size to enable the coal to be dealt with rapidly from the pit-bottom to the surface and the labour reduction effected by riding more than one tub on each deck. The comparison is very marked between pits " D " and " E," " D " being a new colliery. The arrangements in connexion with pit " E " are exceptionally bad, owing to the great waste in shaft-room, which is too large for a single tub, and too small for double-

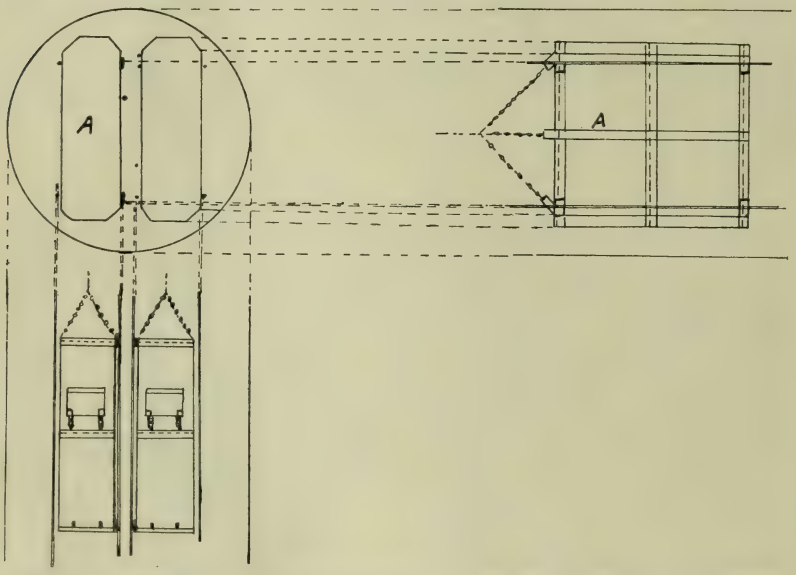


FIG. 2.—POSITION OF CAGES, GUIDES, ETC., IN SHAFT 15 FEET IN DIAMETER. SCALE, 12 FEET TO 1 INCH.

decked tubs. Figs. 1 to 5 show the sizes of the shafts referred to in this table.

It will be noted that the foregoing costs were taken during January, 1921, when the highest wages ever paid in the coal-trade were in force, including the full output bonus.

As the cost of sinking is of much more importance to-day in this coal-field as compared with that of past sinkings, owing to the fact that the seams now awaiting development underlie the heavily-watered New Red Sandstone, the question of utilizing the shaft to its full capacity and not wasting space, without cramping the size so as to interfere with a large output and the ventilation being dealt with, requires very careful consideration.

Table II. contains data as to the comparative cost of shafts sunk by the writer in the Midland Coalfield, the actual sinking cost only being included.

No. 1 Scheme.—The tonnage per winding-shaft of 6 hours 40 minutes from two shafts is assumed to be 2,500 tons, 1,500 tons being wound

TABLE I.—EXAMPLES OF OUTPUTS FROM SHAFTS OF SMALL DIAMETER.

Description.	Colliery "A" (Fig. 1).	Colliery "B" (Fig. 2).	Colliery "C" (Fig. 3).	Colliery "D" (Fig. 4).	Colliery "E" (Fig. 5).
Diameter of shaft	9 feet.	15 feet.	20 feet.	15 feet.	13 feet.
Depth of coal-wind	246 yards.	382 yards.	350 yards.	515 yards.	400 yards.
Description of guides	Rail.	8 of charcoal iron, each 17 feet 6 inches in diameter, and two dead ropes.	8 mild-steel, $1\frac{1}{4}$ inches in diameter.	8 lock-coil, $1\frac{1}{2}$ inches in diameter.	Charcoal iron, $1\frac{1}{4}$ inches in diameter; 3 to each cage.
Number of decks on cage	3	2	2	2, but only one in use.	2
Number of tubs on each deck	1	2	2	4	1
Total coal wound in 6 hours 40 minutes	1,060 tons.	858 tons.	1,106 tons.	700 tons.	386 tons.
Total weight of load on cage when fully loaded with coal	2 tons 6 cwt.	3 tons.	3 tons 10 cwt.	3 tons 10 cwt.	1 ton 10 cwt.
Number of persons employed on each deck:—					
Surface:—Top deck	2 men and 2 boys.	1 man and 1 boy.	2 men and 1 boy.	2 men and 1 boy.	2 men and 1 boy.
Middle deck	2 ,, ,, 1 boy.	Nil.	Nil.	Nil.	Nil.
Bottom deck	3 ,, ,, 2 boys.	2 men and 1 boy.	2 men and 1 boy.	Nil.	3 men.
Total amount paid in wages for surface decking per shift	£9 3s. 7d.	£4 16s. 8d.	£4 13s. 2d.	£2 18s. 6d.	£5 1s. 3d.
Total labour cost per ton	2·1d.	1·35d.	1·01d.	1·00d.	3·15d.
Number of persons employed on each deck:—					
Underground:—Top deck	2 men.	2 men and 1 boy.	3 men.	2 men and 1 boy.	2 men.
Middle deck	4 ,,	Nil.	Nil.	Nil.	Nil.
Bottom deck	2 ,, and 1 boy.	2 men and 1 boy.	3 men.	Nil.	2 men.
Total amount paid in wages for underground decking	£8 4s. 0d.	£4 14s. 1d.	£5 12s. 0d.	£2 14s. 0d.	£3 12s. 1d.
Cost per ton decking underground	1·8d.	1·31d.	1·22d.	0·92d.	2·23d.
Total cost for decking—surface and underground	£17 7s. 7d.	£9 10s. 9d.	£10 5s. 2d.	£5 12s. 6d.	£8 13s. 4d.
*Grand total cost per ton—surface and underground	3·9d.	2·66d.	2·23d.	1·92d.	5·38d.

* These costs were taken for January, 1921, when the highest wages were ever paid in the coal-trade, and include the output bonus.

TABLE II.—COMPARATIVE COST OF SINKING SHAFTS IN THE MIDLAND COALFIELD.

Description.	Shaft No. 1.	Shaft No. 2.	Shaft No. 3.	Shaft No. 4.	Shaft No. 5.
Finished diameter of shaft	15 feet.	15 feet.	15 feet.	10½ feet.	20 feet.
Depth of shaft	216 yards.	167 yards.	265 yards.	50 yards.	529¼ yards.
Date commenced to sink	Nov. 7th, 1905.	March 3rd, 1909	June 13th, 1917	Dec. 10th, 1919.	July 31st, 1913; 24 yards sunk up to Sept. 4th, 1913; recommenced to sink July 5th, 1914.
Sinking completed	Sept. 25th, 1906.	Aug. 2nd, 1909.	April 23rd, 1918.	April 13th, 1920.	July 2nd, 1915.
Sinking contract per yard	£7.	£7 18s.	£10 5s. 6d. plus 18 per cent.	£4 10s. plus 23⅓ plus 18 per cent.	£12 plus 65 per cent.
Sinking excavation—cost only	£1,512.	£1,319 6s.	£3,213 2s. 6d.	£327 10s.	£7,975 14s. 10d. (includes other labour in shaft).
Length of tubbing	54 yards.	Nil.	Nil.	Nil.	23½ yards.
Number of cast-iron wedging-curbs	3	Nil.	Nil.	Nil.	1
Number of curbs	Nil.	9 oak.	21 oak.	4 oak.	15 cast-iron bricking-curbs.
Cost of fixing tubbing, plates, and curbs	£1,451 12s. 11d.	.....	Nil.	Nil.	.....
Cost of tubbing and curbs	£2,018 4s. 2d.	£36.	£198.	£10.	£1,248 10s. 4d.
Cubic yards excavated	6,106.	4,721.	7,491.	795.	24,418.
Total cost of sinking and walling	£4,453 0s. 10d.	£2,532 8s.	£5,500.	£680.	£13,205 13s. 5d.
Measures sunk through	Shale, rock, limestone, and Coal-Measures.	Shale, rock, limestone, and Coal-Measures.	Shale, rock, limestone, and Coal-Measures.	Shale, rock, and Coal-Measures.	Limestone, shales, sandstone, and usual Coal-Measure strata.
Water dealt with	30 galls. per min.	30 galls. per min.	30 galls. per min.	.....	35 galls. per min.
Sinking from	Surface to Low Main Seam.	Low Main to Kilburn Seam.	Deep Soft to Kilburn Seam.	.....	Surface to Deep Hard Seam.
Cost per cubic yard for excavating only	4s. 11d.	5s. 7d.	8s. 7d.	8s. 2d.	6s. 6d.
Total cost per cubic yard for excavating and walling	14s. 7d.	10s. 9d.	14s. 7d.	17s. 1d.	10s. 9½d.

from one shaft and 1,000 tons from the other. The weight of coal per tram is 14 cwt.

The dimensions of the tram body are: length, 4 feet 2 inches; width, 3 feet; height, 2 feet 3 inches; and the overall length of the tram, 4 feet 6 inches. By adopting this size of tram, a clearance of $1\frac{1}{2}$ inches on each side between the tram and the cage is available. The clearance between the centre of the cup-brasses and the cages will be not less than 15 inches. The shaft will be equipped with eight rope-guides. Provision will be made for cables and the rising-main column in addition to the usual signal-cable, lighting-cable, and other small fitments.

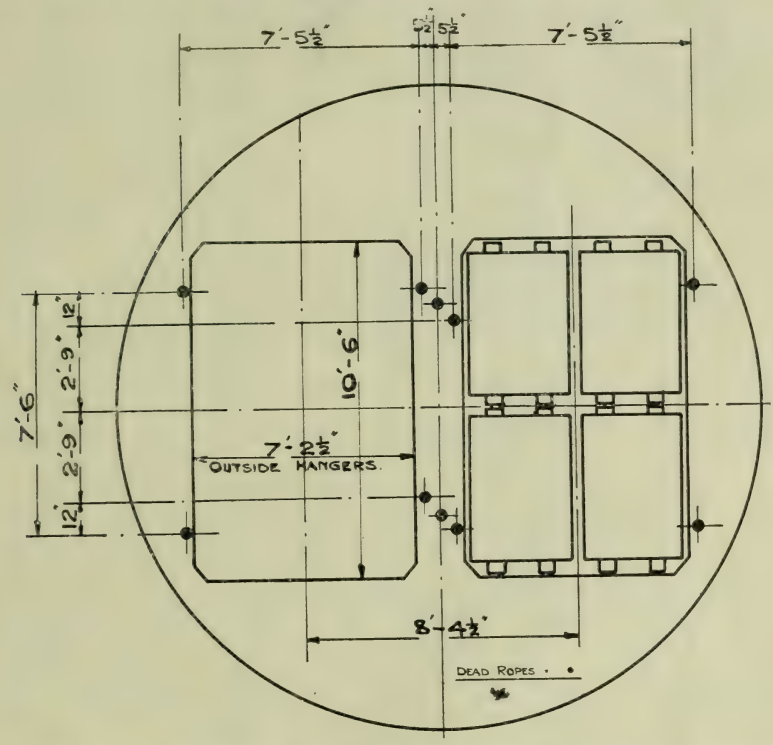


Fig. 3.—Position of Cages, Guides, etc., in Shaft 20 Feet in Diameter. Scale, 6 Feet to 1 Inch.

Fig. 6 shows a shaft with a sufficiently large area to allow for double-deck cages to deal with the above-mentioned tonnage within the specified time. The details are as follows:—

Diameter of shaft, in feet	18
Number of tubs on each deck	3
,, guides in shaft	8
,, decks per cage	2
,, rubbing-guides	2
Time per wind, in seconds	50

As the volume of air for ventilating the mine is taken at a maximum of 400,000 cubic feet per minute, a water-gauge of $5\frac{7}{8}$ inches, with about 600 horsepower, would be required.

Calculating the cost of sinking through the New Red Sandstone at £350 per lineal yard, including the sealing and cementing back of the water, and estimating the depth of water-bearing strata to be sunk

through as 200 yards, it is then shown that to sink two shafts 18 feet in diameter through the ordinary Coal-Measures to a total depth of 700 yards, after passing through the first 200 yards of water-bearing strata, would cost as under :—

200 yards of water-bearing strata with cement tubbing, at £350 per yard	£70,000
500 yards of ordinary sinking, at £1 per cubic yard	20,000
Bricking, bricks, and mortar—500 yards at £1 per superficial yard	22,973
Total cost of sinking	£112,973

The above-mentioned diameter (18 feet) is the finished diameter, and allows for bricking.

If the above amount be multiplied by two, the total cost for the two shafts will be £225,946. This sum is only for sinking and securing the shafts, the object of this paper being to raise a discussion on the most economical size of shaft under the present-day conditions.

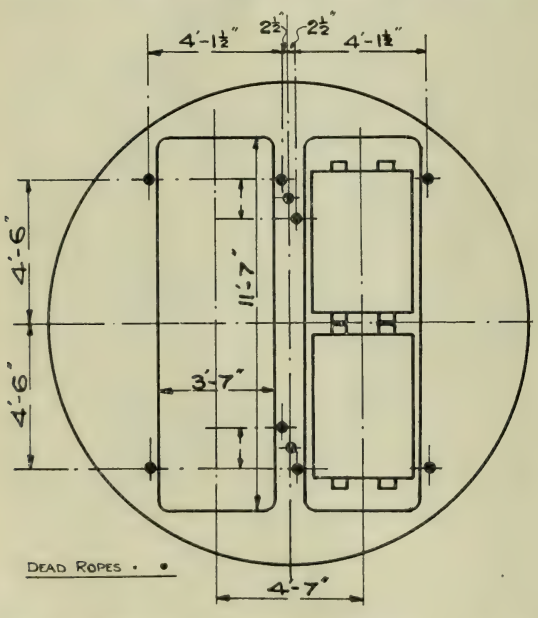


FIG. 4.—POSITION OF CAGES, GUIDES, ETC., IN SHAFT 15 FEET IN DIAMETER. SCALE, 6 FEET TO 1 INCH.

No. 2 Scheme.—It is well worth considering, when laying out a colliery for winning, say, an area of 6,000 acres at a depth of 700 yards, that the tonnage to be dealt with should be wound in the 24 hours, by employing the two shafts with the two sets of screens during the first 6 hours 40 minutes, and one shaft and one set of screens during the second shift of equal length.

If this proposal be adopted, it is estimated that the size of shaft could be reduced from a diameter of 18 feet, as shown in No. 1 scheme, to 15 feet, so that the arrangements would be as follows :—

The clearance between the two cages would be 15 inches inside the cage-conductors, and the number of tubs per deck with the double-deck cage would be two. The weight per tram of coal would be taken at 14 cwt., and the amount of tonnage to be dealt with in the 24 hours would be 3,360 tons.

Fig. 7 shows that a shaft 15 feet in diameter will admit of sufficient room for the use of double-deck cages to convey the above-mentioned tonnage, as under :—

Diameter of shaft, in feet	15
Number of tubs on each deck	2
,, decks per cage	2
,, guides in shaft	8
,, rubbing-guides	2
Time per wind, in seconds	50

As the volume of air for ventilating the mine is taken at a maximum of 400,000 cubic feet per minute, there would be sufficient area in the two shafts just described for the proper ventilation of the mine as in the case of the 18-foot shafts.

Cost.—Estimating the cost of sinking through the New Red Sandstone at £350 per lineal yard, which would include the cost of sealing and cementing back the water, and allowing for the depth of water-bearing strata to be sunk through as 200 yards, it is then shown that to sink two shafts 15 feet in diameter through the ordinary Coal-Measures to a total depth of 700 yards, after

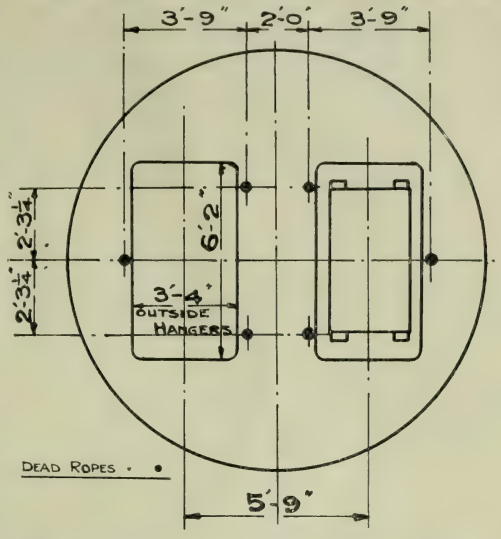


FIG. 5.—POSITION OF CAGES, GUIDES, ETC., IN SHAFT 13 FEET IN DIAMETER. SCALE, 6 FEET TO 1 INCH.

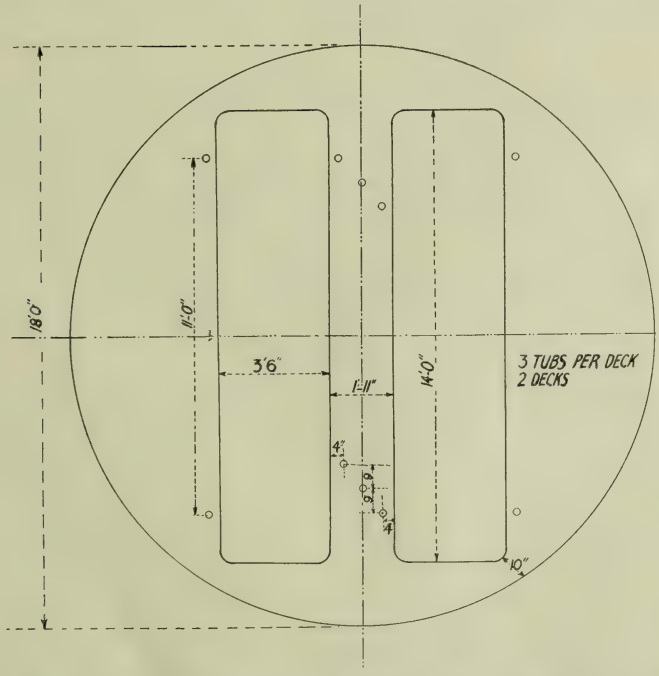


FIG. 6.—DIAGRAM SHOWING ECONOMICAL SIZE OF PIT-SHAFT, 18 FEET IN DIAMETER, FOR WINDING. SCALE, 6 FEET TO 1 INCH.

passing through the first 200 yards of water-bearing strata, would cost as follows :—

200 yards of water-bearing strata with cement tubbing, at £257 per yard	£51,400
500 yards of ordinary sinking, at £1 per cubic yard	14,137
Bricking, bricks, and mortar—500 yards at £1 per superficial yard	19,439
Total cost of sinking	£84,976

The above-mentioned diameter (15 feet) is the finished diameter, and allows for bricking.

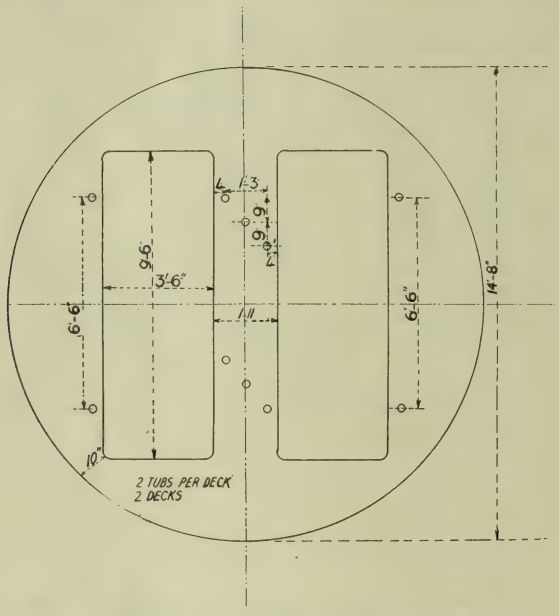


Fig. 7.—Diagram showing Economical Size of Pit-shaft, 15 Feet in Diameter, for Winding. Scale, 6 Feet to 1 Inch.

If the above amount be multiplied by two, the total cost of the two shafts will be £169,952. This sum is only for sinking and securing the shafts.

The President (Major T. P. Barber): This very interesting paper opens up various problems, with some of which I have been called upon to deal myself. If my firm were going to do the work over again, I do not think that we should have a shaft as small as 15 feet in diameter for a depth of over 700 yards. Apart from other considerations, there is the question of ventilation. How can you get an adequate supply of air over an area of 6,000 acres by means of a 15-foot shaft? There is apparently a great amount of monetary saving between a 15 and an 18-foot shaft, but I am under the impression that part of that gain would be lost in the extra time taken to sink the smaller shaft. It is impossible for as many men to work in the smaller shaft as in the larger one, nor can they work quite so effectually.

The question of the size of pit-shafts is one which everybody who has to do with the development of the Yorkshire and Nottinghamshire Coal-field will have to take into consideration. The shafts we are sinking in Yorkshire are 22 feet 4 inches in diameter. We should not, in ordinary

circumstances, have fixed on that extraordinary size, but the shaft was taken over from the Germans, who had originally set it out in metres. We should, however, probably have gone to 21 feet, but the shaft will be, of course, of greater depth—800 or 900 yards. In the case of a large Midland pit, I should not advise anyone to go below 20 feet, and a little above that diameter if it can be afforded.

Mr. Mitton, I notice, shows only two rubbing-guides, which are hardly sufficient for shafts 700 yards deep. My view is that four are required.

Mr. C. Dickinson (Netherseal): One point which struck me was the clearance between the two cages, namely, 15 inches inside the cage conductors. At Hickleton Main Colliery, in Yorkshire, where there are double-decked cages drawing from a depth of about 560 yards, with four tubs on each deck, the clearance between the cages and rubber is only a quarter-of-an-inch. The object is to prevent the cages from oscillating so as to give a blow; it would be merely a rubbing, and there has been no trouble whatever about the clearance. This 15-inch clearance in Mr. Mitton's case seems to go quite to the opposite extreme.

Mr. N. E. Webster (Wrexham): I notice that in No. 2 scheme Mr. Mitton suggests using the two shafts with two sets of screens during the first shift, and one shaft and one set of screens during the second shift. I do not quite follow the idea of working what one may call half a double shift. If he intends to work a double shift, it would surely be better to have both shafts and both sets of screens at work right through than to halve them in the second shift, with practically the full standing charges going on.

Mr. J. Bircumshaw (East Kirkby): It is quite true that it would be advantageous, in working two shifts, to use both winding shafts, but I think that Mr. Mitton's point is to show how the same output can be obtained by means of a smaller shaft. He is making a comparison between 18 and 15-foot shafts, and he shows that by working one of the smaller shafts two shifts the same output can be obtained as from a pair of 18-foot shafts in one shift. Moreover, sinking difficulties are more easily overcome in the smaller shaft, and a saving of about £56,000 would be effected in sinking and walling costs alone.

With regard to the distance between the cages, at Lowmoor it is 11 inches. The cages are double-decked, and carry four tubs on each deck, although only one deck is being used at present. There are two rubbing-ropes, each 2 inches in diameter, and there is no trouble with the cages.

Mr. Dickinson: Do you mean that there is 11 inches of clearance between the rubbing-guides and the cages?

Mr. Bircumshaw: No; the distance from centre to centre of the cage-conductors is 11 inches, the two 2-inch diameter rubbing-ropes being between the two rows of cage-conductors.

Mr. G. Spencer (West Hallam): Mr. Dickinson mentioned that a very large clearance might cause a great deal of oscillation, and probably injury; but, so far as I can see, there may be too much clearance between the cages, and the cages may be blocked out so as practically to be touching the dummy conductors all the time.

Mr. Bircumshaw: At Lowmoor the shaft is 520 yards deep, and the clearance between the cage-conductors from centre to centre is 11 inches.

Between the conductors are two rubbing-ropes 2 inches in diameter, and on the cages are rubbing-boards, which rub on the rubing-rope in case they get near enough to it, and this prevents the cages from fouling. We have been running since 1915, and have had no trouble whatever.

Lt.-Col. G. A. Lewis : It means that you have 5½ inches clearance between the centre-line of the conductors and the centre-line of rubbing-rope?

Mr. Bircumshaw : Yes.

Mr. Spencer : How are the rubbing-boards arranged? I understand they are sometimes fitted down the length of the cage—that is, from top to bottom, with the top and bottom ends so formed as to give a lead and prevent fouling.

Mr. Bircumshaw : The rubbing-boards at the Lowmoor and Kirkby Collieries are fitted across the cages on the top and bottom hoops, and project beyond all ironwork of the cages. The distance between the inner rows of cage-conductors at Kirkby is only 5 inches from centre to centre, the rubbing-ropes lying between. No trouble whatever has been experienced. The point is to keep the rubbing-boards projecting beyond any ironwork of the cages, and there is then little possibility of trouble.

The further discussion of the paper was adjourned.

DISCUSSION OF MR. C. DICKINSON'S PAPER ON "METHOD OF DEALING WITH A SHAFT FIRE AT NETHERSEAL COLLIERY."*

Mr. B. McLaren (Jacksdale) : What was the condition of the beam as regards being wet, or dry, or moist, at the inset previous to the outbreak of the fire?

Mr. R. Laverick (Nottingham) : Has Mr. Dickinson made any further investigations as to the cause of this fire? I cannot quite understand how it occurred. I had a somewhat similar experience some years ago, but the cause was found without any doubt. Two old shafts, each 7 feet in diameter and 14 feet apart, had been used about thirty years previously in working a lower seam. Wooden guides had been in use, and owing to the shafts being so small the buntons had to be let into the walling. One of these shafts was made into an upcast for furnace ventilation, and the other shaft was used as a downcast for an extension of the workings a considerable distance from the drawing shaft. An official found fumes in the travelling-road—which was the intake—and, on investigation, discovered that one of these old buntons had been set on fire by the heat from the ventilating furnace. The fire burnt its way through to the downcast shaft, set fire to another seam of coal behind the walling, and to more wood in the downcast. Fortunately, this was found out just in time, but it took about four days to get the fire filled out. There was no doubt in this case about the origin of the fire, and I should be glad if Mr. Dickinson would tell us whether he has been able to trace the cause at Netherseal. If I remember rightly, some men were engaged in examining the shaft the previous night, and it would be interesting to know what kind of lights they were using, and whether there was any possibility of sparks from these lights having set the beam on fire.

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 345.

Mr. C. Dickinson (Netherseal Colliery): With regard to the first question as to the condition of the beam, the inset at this particular seam is 150 yards from the shaft-top, and the tubbing extends to a depth of 95 yards. The whole of the tubbing-joints were leaking constantly—not by spurts, but drops—and there was also a leakage from the surface, so that the beam was constantly wet. Its wetness, I think, accounts for the danger being less than otherwise it might have been. It was so wet that the outer part of the beam could not ignite. It was the movement of the cages which shook this beam after it had been converted into charcoal internally, when some sparks fell out. The beam was of oak, and was originally put in when the inset was made in the seventies.

With regard to the origin of the fire, this inset was in the Main Coal Seam, which is notoriously liable to spontaneous combustion, and, as the paper records, there have been a number of fire-stoppings put in. Some years ago—perhaps thirty or forty—a fire took place near the upcast shaft, and so fierce was it that the pits had to be sealed up. Traces of this fire were found on the road-sides when we were working at the later occurrence. During 1915 or 1916 on one of the main roads 150 yards from the shaft a fire broke out in the pillar along the side of the road, and extended for 100 or 150 yards, but was dealt with at the time. The seam was almost exhausted, and when an influx of water occurred it was not thought worth while to continue operations owing to the small quantity of coal that remained. Brickwork stoppings immediately surrounding the shafts were put in, and, knowing the great danger of fire—which had actually occurred about 200 yards away within the previous twelve months—I was very careful to put in these brickwork stoppings exceedingly well. I was therefore astounded when I found fire; but what especially surprised both me and my staff was the fact that, when we got down to the fire and found a visible area of fire measuring 10 feet wide and 10 or 12 feet long, a few inches from the shaft side a current of air was going over it into the workings, but we could not tell where it went. We took a canary down with us to guide us in our search. We could not find any smoke in the upcast shaft, but near the stoppings above the top of the seam a crack, as long perhaps as an ordinary lead-pencil and twice as thick, was found. There was no smoke and no smell, and it was only with the assistance of the canary that we were enabled to locate the crack, but where the air went to I do not know.

With regard to the examination of the shaft, this was routine work, and as it is a safety-lamp pit no naked lights are allowed to be used. We have had no further trouble since the incidents described.

Mr. McLaren: It is very disquieting to think that after a seam has been abandoned and sinking continued to a lower one, a fire may suddenly break out without warning. It shows the necessity, where the seam is subject to gob-fires, of removing all old timber and of adequately sealing the inset. If it is necessary to keep the inset open for any reason, it ought to be frequently examined for any signs of fire.

Mr. Dickinson: I draw a different lesson from that, namely, not to have any wooden conductors or stays in the shaft.

ELECTRIC WELDING OF A CAST-IRON ROPE-DRIVE FLYWHEEL.

By N. E. WEBSTER, O.B.E., M.C.

Owing to a disastrous fire that destroyed the power-house of the Broughton & Plas Power Coal Company, Limited, which supplied the power for three collieries, including the pumping (which was maintained continuously throughout the 24 hours of the day), the pits were placed in grave danger of flooding. The fire occurred at 1.30 p.m. on April 18th, 1921, and was caused through a volunteer workman having dropped a match into the rope-race.

As soon as the engines and other remaining ironwork had cooled down a little, a preliminary examination was made, which showed that all the electrical portions of the three 200-kilowatt sets contained in the building were ruined, but that the steam ends of the sets had not suffered irreparable damage. By next morning sufficient *débris* had been cleared away to enable the machinery to be thoroughly examined, with the result that of the three sets two were found to be repairable. One of these, a Robey compound non-condensing set, with cylinders measuring $15\frac{1}{2}$ and $22\frac{1}{2}$ inches, and having a 14-foot flywheel, rated at 340 brake-horsepower and normally driving by means of ten $1\frac{1}{2}$-inch cotton ropes a 200-kilowatt Scott-&-Mountain generator, was tried under steam and found to be workable, the most serious damage being a series of six cracks in the rim of the 14-foot wheel.

The rim weighed about $4\frac{1}{4}$ tons, and had a peripheral speed of 3,800 feet per minute, the unit stress in the rim being just under 400 pounds per square inch, which gives a factor of safety of no less than 50 in 1 so far as the rim section itself is concerned. The total weight of the wheel was about $6\frac{1}{2}$ tons, including the boss and eight arms. This peripheral speed is, of course, comparatively low, the driven wheel being 31 inches in diameter and giving a dynamo speed of 460 revolutions per minute (5·4 to 1). The drive was arranged at 25-foot centres, and as the horsepower transmitted by a $1\frac{1}{2}$-inch rope under such conditions was laid down at 32·7, it was possible to do away with the outer rope on each side, if necessary, without imposing too great a duty on the others.

It was decided to purchase a new generator, and to have the wheel electrically welded, provided that the welders would guarantee their work. The first firm who inspected the job declined to do this, however, since the material was cast-iron, for which their plant was unsuitable. Another firm of welders was therefore called in, and after an inspection they stated that they were willing to guarantee the success of their method.

The first essential in dealing with cast-iron is to deliver and maintain a critical degree of heat at the weld so as to ensure the proper fusing of both the parent and the deposited metals without any risk of burning or slagging due to excessive heat. It may be noted that the higher the carbon content of the metal, the lower the proper welding current will have to be, and *vice versa*, or incomplete fusion will result. The castings, in order of simplicity to weld, are mild steel,

white cast-iron, grey cast-iron, malleable cast-iron, high-carbon cast-steel, and non-ferrous castings such as aluminium, bronze, etc.

The conditions enumerated above are successfully fulfilled by means of a special flat compound low-voltage generator, which feeds the circuit through a constant-current controller in the form of a solenoid-operated resistance. This solenoid is in series with the arc, the current through the arc being controlled by automatic variation of a variable resistance in response to the pull of the solenoid, which compresses or relaxes a series of copper and carbon plates. The ordinary carbon resistance can be used, but is not successful, since the plates become very dirty, thereby causing excessive heating.

There is, in addition, a pilot motor, which is operated by a switch at the welding-tool handle, by which a further adjustment in resistance can be made, so regulating the amperage that the operator can change the arc current without leaving his work. This is very essential when

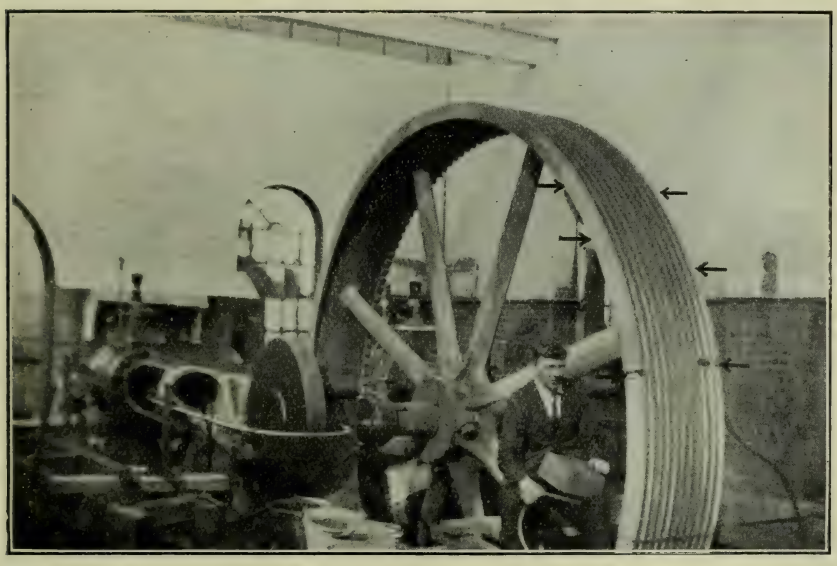


FIG. 1.—ROBEY COMPOUND SET AND FLYWHEEL IN GUTTED POWER-HOUSE. THE SIX CRACKS CAN JUST BE DISCERNED ON THE FACE OF THE WHEEL, AS INDICATED BY THE ARROWS.

building up a large patch, as the heat increases with the deposition of the metal, owing to the path of the current lying through the deposit; and as it is essential, in order to ensure a successful patch, that the temperature of the deposit should be kept as low as possible compatible with complete fusion, a gradual reduction of arc current is necessary. This is known as the Wilson system, or constant-potential type, in which an open-circuit voltage, not exceeding 35 volts, is used. Inasmuch as the current control is automatic, it differs in this respect from—

(1) The drooping characteristic type, with a voltage of from 60 to 75 and a current varying in inverse ratio to the voltage; and

(2) The constant-potential type, with a voltage also of from 60 to 75, but with the current controlled by a permanent fixed resistance in series with the arc, the percentage variation due to work resistance being only a small proportion of the total resistance.

Both of these systems are designed to give constant energy or heat in the arc, but not in the weld, and either much heat is dissipated in

the arc, or, owing to the high voltage used, there is grave danger of porous and brittle welds. A low voltage at the arc renders it impossible for the operator to draw out a long arc, since, of course, the voltage across the arc increases as the arc lengthens. The result of too long an arc is excessive heating, with consequent ruin and slagging of the metal deposited. With a low voltage the external appearance of a weld is a sure guide to its value, and it can be safely assumed to be internally free from any dangerous slag or oxide inclusions, whilst the welder has the maximum voltage that can be handled without burning the parent metal, or causing porosity or a brittle weld, so that a weld of full tensile strength, and not merely a deposit, is obtained.

To ensure full tensile strength, different types of electrodes are used, varying in chemical composition according to the metal to be dealt with. They are not, as in some other systems, coated with any "fluxing" or oxidation-preventing mediums. The Wilson system also

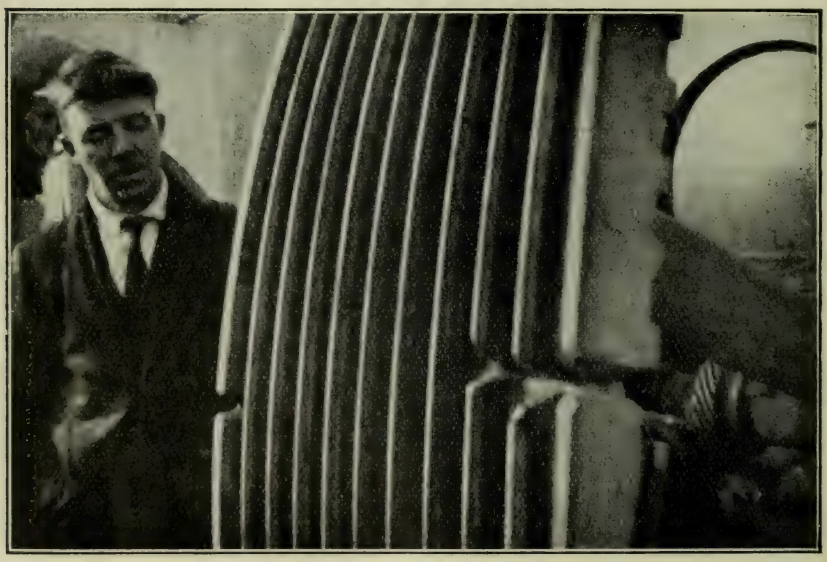


Fig. 2.—Face of Flywheel, the Principal Cracks having been cleared by a Pneumatic Chisel into a V, in order to expose the Surface of the Metal.

differs from all others in that the job is positive and the electrode negative, which ensures deeper penetration of the deposited metal, since the positive is actually at a slightly higher temperature than the negative in all systems.

In other systems of electric welding, it is generally requisite, when dealing with cast-iron, to drill holes into the parent metal and to insert steel studs for the adhesion of the deposit, thus forming a series of bridges and not one complete mass with the cast-iron of the job itself. With the apparatus described, however, the added metal becomes part of the whole, and in all cases of which I know it has stood as such without the slightest sign of any likelihood of departure from the parent metal.

It should be mentioned that all the cracks in the flywheel were first cleared out with pneumatic chisels into V shapes, so as to enable the operator to get his electrode into proper contact with all the surfaces,

and from the photographs (Figs. 1 and 2) it will be seen that their extent was considerable.

The work was subsequently inspected and passed by the insurance company; and it is interesting to note that the only failure of which they knew was that of a crank-shaft of a gas-engine, which, owing to the heavy and unequal stresses imposed upon it, requires careful welding with a special high-tension electrode. Nevertheless, by this particular system the 1½-inch diameter propellor-shaft of a 4-ton Belsize lorry, which broke whilst leaving the colliery, was welded on the spot, and is now running in good condition to-day.

As an additional safeguard, the outer rope-groove on each side of this flywheel has since been wound with about 1,500 yards of No. 13 gauge mild-steel wire, put on under tension, and subsequently soldered down and made secure with tin strips every foot apart.

The engine was subsequently run up to quarter speed, and after a short time tested, this operation being repeated with increased speeds, and eventually, no signs of weakness being evident, was put under load. It has since been running for 23 hours out of every 24, the longest consecutive run being one of 132 hours, and the flywheel appears to be in every way absolutely sound.

I am indebted to Messrs. Allan, of Hamilton Square, Birkenhead, for permission to examine their plant and for assistance in preparing this paper.

Mr. C. Dickinson (Netherseal): What time was occupied in the operation.

Mr. N. E. Webster (Wrexham): Three days were required to complete the job. The men worked about ten hours per shift, so that thirty hours were occupied in actual working. It was possible to carry on simultaneously and without hindrance the three operations of chipping-out, welding, and facing-up the welds with an emery wheel. The chipping-out occupied the longest time.

Mr. G. J. Binns (Duffield): The operation has been described so fully and so clearly by Mr. Webster in his paper that I have no questions to ask, but should like to remark on the extreme value of papers of this character, which tell us what has actually been done. When any member has had to perform some unusual operation in connexion with his pit—even if the operation has not been altogether successful—it is very useful for the facts to be made known; but when, as described in Mr. Webster's and Mr. Dickinson's papers, the operations have been quite successful, it is particularly desirable to have them on record: for it must be remembered that the *Transactions* go all over the world, and the information given may be of infinite value to people perhaps 14,000 miles away.

Mr. J. Bircumshaw (East Kirkby): It would be interesting if the cost of this welding operation were put on record.

Mr. Webster: The total cost was £84, including material and labour for wire-winding the two rope grooves. The cost of the actual welding operations was £65. A new wheel would have cost £400, and delivery was offered at from ten to twelve weeks.

Mr. B. McLaren (Jacksdale): The advantages of electric welding have been proved in a small way in my own experience. We had recently a

coal-cutting machine which on getting into a certain position slipped out of control and practically had its back broken. We had it electrically welded, and it is working now as well in every respect as ever it did before. In former days a new machine would have had to be purchased to take its place.

The President: Which of the three systems of welding was employed?

Mr. McLaren: I cannot tell that, but I will obtain the particulars if the discussion is adjourned.

Mr. J. Platt (Blackwell): Can Mr. Webster inform us why in the system he describes there is no coating on the electrodes? We had a case during the coal stoppage in which welding was very successfully adopted. A valve-box on the 30-inch winding-engines had cracked, and had been leaking slightly for some time. The stoppage enabled us very carefully to investigate the matter, and we called in the welding people, who welded quite a huge crack. It proved to be a complete success.

Mr. Webster: The coating on electrodes is generally regarded as a fluxing medium. It is, however, much more generally an attempt to prevent oxidation by surrounding the molten tip of the electrode with a protective coating.

In all high-voltage methods of welding it is possible to draw out too long an arc; in fact, unless the operator's hand be miraculously steady, such occasional over-lengthening of arc is bound to occur. The result is that the nature is burnt out of the molten beads at the electrode tip, and the beads inevitably oxidize in their passage through the long arc, resulting in a slagged deposit lacking in all the essential properties of a reliable weld. The coated electrode is an attempt to minimize this effect.

Owing to the low voltage of the Wilson system and the automatic control through the solenoid-operated resistance, the current is cut off the arc at a predetermined length well under the safety limit, and varying in accordance with the composition of the electrode in use at the time, no such burning or oxidation being possible.

The further discussion of the paper was adjourned.

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THE INSTITUTION OF
MINING ENGINEERS
PERPETUATES THE MEMORY OF ITS
MEMBERS WHO GAVE THEIR LIVES
FOR THEIR COUNTRY 1914-1918

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

GENERAL MEETING,

HELD AT THE SOUTH GROVE SECONDARY SCHOOL, MOORGATE, ROTHERHAM, OCTOBER 22ND, 1921.

LT.-COL. H. RHODES, PRESIDENT, IN THE CHAIR.

DEATH OF SIR WILLIAM GARFORTH, LL.D.

The PRESIDENT: I deeply regret that my first official duty is a very sad one, and one that has become only too common during the last eighteen months or more. I refer to the death of Sir William Garforth, whose works as a mining engineer are well known to all present, so that I need not enlarge on them. Wherever coal-mining is practised, the name of Sir William Garforth is known, chiefly from his researches into the question of the use of stone-dust in preventing the spread of explosions, and also from the fact that he was one of the pioneers in the introduction of mechanical coal-cutters into South Yorkshire, if not into the United Kingdom. In proposing a vote of condolence with Lady Garforth and family, I should like to add my own sense of personal loss of an old friend. Sir William was one of the oldest surviving Past-Presidents of the Institute.

The resolution was carried, all the members standing.

PRESIDENTIAL ADDRESS.

BY LT.-COL. HARRY RHODES, M.INST.C.E.

A privilege that I have looked forward to ever since August 25th is to give you a brief Inaugural Address on taking the chair as President of this Institute. In deciding on a subject on which to address you on this occasion, I naturally turned to the Presidential Addresses read during the last few years, and particularly to that of my late father, Mr. Charles Rhodes, which was delivered before this Institute in Barnsley, on October 31st, 1888, almost exactly 33 years ago.* I was struck with the coincidence that it should be exactly a generation ago, and I therefore went further back, and found that the Midland Institute was founded as far back as 1857, 31 years before my father read his Address, which is practically another generation. It was then known as the "South Yorkshire Viewers' Association," and, as it is two generations since it was formed, I thought it would be interesting not only to review my father's Presidential Address but also the first Presidential Address read in 1858.

* *Trans. Mid. Inst.*, 1887-1889, vol. xi., page 253.

The South Yorkshire Viewers' Association was formed as the result of a meeting held at Barnsley on June 9th, 1857, and the circumstance that led to its formation, as far as I can ascertain, was the disastrous explosion which took place at the Lund Hill Colliery in February of the same year, when no less than 189 lives were lost, and which I believe I am correct in saying was the greatest disaster that had ever occurred, up to that date, in the history of coal-mining. As a result of that disaster, and from the investigations that were made into the causes of it, a meeting was held at the Royal Hotel, Barnsley, on June 9th, 1857. The first words in Part 1 of the *Transactions* of the South Yorkshire Viewers' Association read as follows:—

"At a Meeting of Colliery Viewers and Managers, convened by circular, to take into consideration the propriety of establishing an Association having for its object 'the more general diffusion of practical and scientific knowledge on the working and ventilation of coal mines.'"

If I was asked to describe what was the object of this and similar Institutions, I could not describe it in better words, but I will return to this point later.

Present at that meeting were a number of gentlemen, some of whose descendants are still carrying on business as mining engineers. One in particular, I believe—the late Mr. E. Beacher, of Thorncliffe Colliery—has two if not three sons still in practice. All the gentlemen who were present at that preliminary meeting became, according to the first list, members of the South Yorkshire Viewers' Association, with the exception of Mr. Mitchell, who I take it would be the grandfather of the late Col. Mitchell, and father of the late Joseph Mitchell, who were both Presidents of the Midland Institute. The first President was John Thomas Woodhouse, a mining engineer whose headquarters were at Derby and Westminster, and I think I might safely say he was the first of the great mining engineers that the Midland Coalfield has produced. He was a very farseeing man. I have in my possession the working-plans of the Holmes Colliery, about half-a-mile from Rotherham, which was sunk in 1858 to a depth of 338 yards, and these plans show the colliery to have been laid out by Mr. Woodhouse to be worked by the longwall method. Unfortunately, through circumstances over which he had no control, other advisers were called in, and the system of working was altered, with results that anybody familiar with the working of collieries in the immediate neighbourhood of Rotherham knows only too well at the present day.

Other members of the Institute at that time were the late Mr. John Chambers, of Chapeltown, father of the late Mr. Arthur Chambers, who became President of the Midland Institute; Mr. Thomas Dunn Jeffcock, father of the late Mr. Thomas W. Jeffcock, who was also President; Mr. W. P. Maddison, who was the second President of the Midland Institute after it changed its name. Other members were Mr. Parkin Jeffcock, who, to the knowledge of most of you, was killed at the Oaks explosion in 1866. Anybody passing near the yard of the Oaks Colliery can now see a monument put up a few years ago by his sister to the memory of him and the other unfortunate people who lost their lives. It is well worth while to stop and have a look at that monument.

There are other well-known names in the list, but except to the older members they convey very little, except perhaps that of Mr. G. C. Greenwell, whose address is then given as Radstock Colliery. In addition to being a founder of the South Yorkshire Viewers' Association, he was one of the original founders of the North of England Institute of Mining

and Mechanical Engineers five years before, namely, in 1852, so that our association with the North of England Institute goes back a very long way, although we did not come into absolutely close contact with it till some thirty years later.

Turning now to Mr. Woodhouse's Presidential Address, delivered a year after the formation of the Association, he deals very briefly but very thoroughly with the reasons for the formation of the Society—reasons which I have just alluded to. He gives a brief description of the principal seams of coal worked from Derby to Leeds, which in those days, as now, were the Barnsley Bed and the Silkstone. Not only does he review the collieries working those seams at that time, but he goes back a further thirty years, to 1827, when he states his practical experience began, so that the Presidential Addresses delivered before this Institute practically cover 100 years. He refers in his Address to the old belief among the so-called practical men that coal did not exist underneath the Magnesian Limestone, but he says it was, of course, well known to geologists that the coal does exist underneath it, and that there is no reason why coal should not be worked, at some time or other, in the neighbourhood of Conisborough. He also refers to the enterprise of the Duke of Newcastle in following the geologists' advice and sinking his Shireoaks Colliery, which proved the coal well within the area covered by the Magnesian Limestone in the same year that he read the Address, namely, in 1858.

It is rather interesting to note the progress of the Institute, so far as its membership and its income are concerned. In 1857 there were 14 honorary members, 3 life members, and 32 members. The income was £166, and the expenditure £55, leaving a balance on the year's working of £111. I am afraid we have never been able to beat that record, and I do not think we ever shall; but I should explain that Mr. J. T. Woodhouse gave a sum of one hundred guineas, which entitled him to become a life member, and that amount is included in the year's income.

Passing on to 1888, the number of members had increased to 167, the income was £402, and the expenditure £203, leaving a balance on the year's operations of £199. On July 21st, 1921, we had 525 members, including 35 subscribing firms; our income was £1,644, and our expenditure £1,303, giving a balance of £341.

Many eminent gentlemen followed the late Mr. Woodhouse as President of the South Yorkshire Viewers' Association, and in July, 1869, this Association was amalgamated with the Midland Institute of Mining Engineers.* As time went on, it was evidently thought that the Institute had not a sufficiently embracing title, and in 1875, in order to widen the scope of the Institute, the name was again changed to the present title of "The Midland Institute of Mining, Civil, and Mechanical Engineers."† Unfortunately we do not possess in our Library a set of the *Transactions* of the South Yorkshire Viewers' Association for the years 1857 to 1869.

The first President of the Institute was Mr. T. W. Embleton, who held office on two subsequent occasions, Mr. W. P. Maddison coming between Mr. Embleton's first two periods. I can just remember Mr. Embleton, but, with the exception of Mr. Maddison, I had the honour of knowing the whole of the other Past-Presidents, namely, Mr. Richard Carter, of Barnsley, Mr. Thomas Carrington, Mr. T. W. Jeffcock, Mr. A. M. Chambers, of the well-known firm at Chapeltown, Mr. C. E. Rhodes, Mr. Joseph Mitchell, Sir William Garforth, Mr. John Nevin,

* *Trans. Mid. Inst.*, 1869-1870, vol. i., page 11.

† *Ibid.*, 1874-1876, vol. iv., pages 134-140.

Mr. George Blake Walker, Mr. W. H. Chambers, Mr. John Gerrard, Mr. H. B. Nash, Col. T. W. H. Mitchell, Mr. J. R. R. Wilson, Mr. W. Walker, Mr. M. H. Habershon, Mr. J. Hodges, Prof. F. W. Hardwick, Mr. Walter Hargreaves, Mr. C. C. Ellison, Mr. W. D. Lloyd, and Mr. J. H. W. Laverick. Unfortunately the great majority of these gentlemen are no longer with us, and I have not the time either to enlarge on their services to the profession, or upon the services of those who happily survive, except to say that it is a list of eminent names, and one with which I am proud to be connected. I only hope that I shall be able to leave the Institute, at the end of my period of office, in at least the same efficient state in which I now find it.

In order to deal further with the history of the Institute, I then, as I stated, turned up my father's Presidential Address. He first introduces the objects of the Institute, which no words of mine can enlarge on, as I think that the few words I read from the late South Yorkshire Viewers' Association at the beginning are quite sufficient. He then enters into the reasons why people should join an Institute. He says it is very probable that when people are tied to one colliery all their lives, through no fault of their own, " the natural tendency of the minds, with persons so placed, is to gradually assume a kind of hazy notion that the be-all and end-all of mining operations is to be found in the district or colliery with which they are connected." If that was true then, it is equally true now. We have moved a great deal, however, since 1888, but I find that he goes further, and on the same page suggests that more or less informal meetings should be held in which stewards, deputies, and, I presume (although he does not mention them), students, should join. As you know, that suggestion was met during the next year or two by the introduction of the present classes of Members, Associate Members, Associates, and Students. With regard to lectures, which he suggested should be arranged under the auspices of the Institute to people actually engaged in manual operations, the facilities for gaining instruction have, of course, increased enormously since 1888. Lectures are now provided by a number of educational agencies, but we welcome them, and wish to see as many as possible of what one might, without any derogatory effect, call the lower grades of mine workers join the Institute, for there is room for them, although they have facilities such as were not dreamt of in 1888 for acquiring information from other sources.

He also foreshadows federation, which he was able to bring about during his term of office in 1888-1889. You will recall that the various Institutes in England, with the exception of the South Wales Institute, the Manchester Geological Society, and the North Staffordshire Institute of Mining and Mechanical Engineers were federated in 1889. Since that date the Manchester Geological Society and the North Staffordshire Institute have come in, and also the Mining Institute of Scotland, and the only body connected with coal-mining that is not now a member of The Institution of Mining Engineers is the South Wales Institute of Engineers. It is, of course, within the knowledge of members that during the last three or four months a working arrangement has been come to between The Institution of Mining Engineers and The Institution of Mining and Metallurgy, and I think in that arrangement there are seeds that will bear considerable fruit in advancing the profession of mining engineering in general.

My father then goes on to suggest the topics, or the subjects, on which papers might be read. He refers first of all to ventilation, on which

subject we have had some very valuable papers during the last few years. It is not necessary to mention the names of those who have written them, but they have been extraordinarily valuable. In the next paragraph he says that he believes in the old saying "An ounce of practice is worth a ton of theory." Well, nobody can disagree with that, so long as the theory that you have is applied in your practice, for you must not keep it in watertight compartments. In that respect, putting in a word of my own, I should like the Institute to have some papers that deal more with the absolute practical side of mining. For instance, following one of my father's suggestions, anybody who has had a creep where he thinks he has left an adequate pillar, and who finds that he has not, might very well put his pride in his pocket and describe the cause which led to the creep, so as to give a little guidance to other people who have similar problems to deal with. My father next deals with the question of electricity. Even in 1888 he says: "When one looks at the enormous strides that the science of electricity has made during the last few years, one can readily believe in almost anything taking place in respect to its use within a very short time." Considering that these words were said within four years of the first application of electricity underground, which I believe was by the late Sir Francis Brain in 1884, only 37 years ago, at the Trafalgar Colliery, Forest of Dean, the progress had been remarkable; but the progress since then has been still more remarkable, although it has had from time to time various setbacks. As far as I can ascertain, the first application of electricity in this district was at St. John's Colliery, where I read in old *Transactions* the pumping plant got to work in February, 1888. But pumping, although a very important item in itself, is only one of many operations connected with collieries, and the first colliery in Yorkshire, I believe, to seriously adopt electricity for its motive power was Hickleton Main, which installed the continuous-current system for its main haulage as early as 1893. Progress for some years was not so rapid as my father apparently anticipated, for I find that as recently as 1899 I read a paper on strap-ropes, and compared them with electricity, to the disadvantage of the latter. But still we are all open to be converted, and I have been converted since, although, when the Silverwood Colliery was laid out the same year, my father and I contemplated working our haulage with strap-ropes. Of course, what gave the great impetus to the use of electricity underground was, I will not say the introduction of the polyphase system, but the development of it, which made polyphase current practically as easy to deal with as continuous current. The late Mr. George Blake Walker took a keen interest in the introduction of electricity in the early years, and read a paper on the subject towards the end of the year 1888. Mr. W. H. Chambers told me the other day that Mr. Blake Walker went over to Germany somewhere about then (unfortunately, I have not the exact date), and came back and said that absolutely *the* power of the future was polyphase current; but, although he was quite convinced that it was the power of the future, he would not undertake the responsibility of putting it in himself. Anyway, by 1900 its advantages for colliery use were well known, and large plants began to be installed. I believe that probably the biggest plants put down up to that date were the Westinghouse installations at the various pits of the Staveley Company, and as a result of the working of those installations we decided at Silverwood to abandon our old strap-rope idea and go in for alternating current.

My father says :—

"In addition to the use of electricity for hauling and pumping, it seems to be almost a certainty that before long it will be the chief means of lighting collieries, not only from fixed lights around the pit bottom and in the main roadways, but also in the form of portable lights for the use of the workmen, as the question of a portable miners' electric safety lamp is now almost solved. I have seen one or two which nearly meet every requirement that is necessary in such a lamp except one, and that is the heavy first cost."

I am not quite sure that that disadvantage has been quite removed even to-day. But, for the interest of anybody who would like to see them, I have here three of the lamps that have been in Aldwarke Main Colliery office ever since that date, from an examination of which it is quite evident that even in those days a great deal of thought had been given to the subject.

My father then proceeds to deal with the question of coke-making in beehive ovens and the recovery of by-products. His remarks are chiefly confined to beehive ovens, as the early prejudice to the retort type of oven had not then been overcome. I think we might safely say that, although there are a few working in the district, beehive ovens are as dead as the dodo, whilst enormous progress has been made in the design and working of the retort types. He then suggests that the Institute should take up the question of testing explosives, as it had, in 1882-1884, taken up the question of testing safety-lamps, and experiments were begun on a small scale in the same year by him at Aldwarke, which led eventually to a Joint Committee being formed with the Midland Counties Institution, who published a report on the subject.

At the Council meeting held this morning, we were discussing the times and dates of the various General Meetings to be held during the ensuing year. I see here that my father suggested that an excursion might be arranged during the session. We used to have excursions before the war, and, in conjunction with the President of the neighbouring Institute, we shall start these excursion meetings again; in fact, I have already mentioned the subject to Major Barber, the President of the Midland Counties Institution of Engineers, who will be very glad to co-operate with us in starting these functions, and I hope that we shall have an excursion meeting in April or May.

I could, of course, enlarge at great length on the various points that were brought forward in my father's Address, but bearing in mind the words with which he begins—"I fear that to a great many of you Presidential Addresses are in the main such a well-worn theme that I shall only weary you"—I will just touch on one more point which he raises in the last two pages. He says :—

"Times are changing with marvellous rapidity, and those who are not prepared to go with them will be left behind in the race; and in no case is this more true than in coal mining. Increasing difficulties will confront the mining engineer year by year. Coal will have to be won at very much greater depths, and consequently increased skill, knowledge, and experience will be necessary if the difficulties to be faced are to be successfully surmounted."

"We are yet far from being played out, and I contend that it is our bounden duty to endeavour, as far as lies in our power, to give the benefit of our own experience and training to those who surround us now and who will probably succeed us, and great good must necessarily be conferred upon the rising generation by having handed down to them, recorded in print, the results of the deliberations of such Institutes as ours."

I do not know that I need enlarge any further on that point. The records now handed down in print are, of course, much more voluminous than they were in those days. Not only have we got 33 years more of our own *Transactions*, but we have the benefit of 32 years' *Transactions* of all the Federated Institutes. I think no one can deny that the Midland Institute, in the past 64 years, under its various titles, has done a great deal for "the more general diffusion of practical and scientific knowledge on the working and ventilation of coal mines." Those words differ literally from those appearing on the certificate of Membership of The Institution of Civil Engineers, which point out that "the art of the civil engineer is the art of directing the great sources of power of nature for the use and convenience of man"; but I think that our aims are practically the same, although they are expressed in different words.

You will perhaps expect me to say a few words on the economic situation. I do not think that a meeting of an Institution such as this is the place to discuss economic problems; but since I do refer to them, I should just like to make one little point—that we are always seeing it stated in the press that "wages must come down." That is not, I think, the right way of putting it. No one wants to see wages come down, but we do want to see the cost of production come down. If we reduce wages by half, and a man does half as much work, we are as we were before; but if, whilst keeping wages where they are, we can get twice as much work done, we are so much better off. It is, therefore, somewhat of a misstatement to say that wages must come down: what we want is the cost of production to come down, which is a very different thing; and the only way that the cost of production can be brought down is by the co-operation of such societies as ours with the other partners in our great industry.

Mr. J. H. W. Laverick (Tursley Park Colliery): The President's interesting and historical Address is, I think, on an occasion like this, most useful, in order that we may review the past. We all realize that mining is a science that must progress, but it will never advance if we keep in narrow grooves and do not come out into the open, and assist one another in connexion with the work that we have daily in hand. This is the great value of an Institute such as this. We attend these meetings and give one another the benefit of our experiences—for the total sum of these experiences all helps on the progress of the science of mining, in which we are all engaged.

Mr. E. W. Thirkell (Aldwarke Main): I have been reading in Volume XI. of the *Transactions* of the Institute (1887-1889) the Addresses of Mr. Charles Rhodes and other Presidents. There are in that volume three most interesting papers which are well worth studying. They are the Addresses of Mr. Rhodes and Mr. T. W. Embleton (which is very interesting and historical), and the paper by Mr. G. Blake Walker on "Mining in the Middle Ages." We have to avail ourselves of the experience of those who have gone before, and we owe a very deep debt of gratitude indeed to the pioneers of early mining, who laid the foundation for us to build upon, but not without great cost and loss to themselves. This is shown by the following extract from Mr. Embleton's Address:—

"1649. Master Beaumont, a gentleman of great ingenuity and rare parts, adventured into our mines (Northumberland) with his £30,000, who brought

with him many rare engines not known then in these parts, as the art to boore with iron rodds to try the deepnesse and thicknesse of the coal, rare engines to draw water out of the pit, wagons with one horse to carry down coals from the pits to the staithes to the river. Within a few years he consumed all his money, and rode home on his light horse."

I venture to say that that £30,000 was not lost. It certainly was lost to Master Beaumont, but it was given to the country for the benefit of those that had to come after him. It is interesting to note in Mr. Embleton's Address references to the action of Parliament in fixing the price of coal, in order that there should be good wages for the miner.

DISCUSSION OF MR. STANLEY NETTLETON'S PAPER ON "THE FRICTION COEFFICIENT OF MINERALS."*

Prof. Granville Poole (Leeds University): The preparation of coal for the market and for coke-ovens is an important matter to-day, and will undoubtedly be of even greater importance in the future. Washeries are expensive to install, and require large quantities of water, but fortunately there are compensating advantages. Any device which is an improvement on our present system will be welcomed.

In comparing Figs. 1, 2, and 5, it appears that a "typical Coal-Measure shale" might have a very different coefficient of friction to that of the Beeston coal, and that a "black shale from the Coal-Measures" might have practically the same coefficient. This at once complicates separation by this method. It is possible to have several kinds of shale mixed with the coal from bands in the seam and from the roof.

Fig. 3 is interesting as showing the effect of time on the coefficient of friction. The coefficient of coal four months after breaking is greatly reduced. Why is this, and what is the object of the experiment? No one wants to keep coal at the colliery four months if he can avoid it. With regard to the action of time on stone, as indicated in Fig. 4, it appears that the coefficient is reduced quite appreciably after four days, and in this connexion the figure might be somewhat misleading. Another factor enters, namely, the effect of weathering. If uncleaned coal is tipped for four months, it may be found that the weather has had much greater effect in disintegrating the shale than the coal, with the result that the coefficient for the shale will be increased rather than diminished, and it may then be much easier to effect separation by this method.

The dry separation of shale from coal, by utilizing the difference in the coefficient of friction, is not a new process. The earlier form of separator consisted of a series of inclined planes with cross slots at right-angles, the opening of the slot being adjustable. Classified mixed material gravitated down, the coal jumped over the slot owing to its greater velocity, and the stone, sliding more slowly, fell through the slot. In the Spiral cleaner (a model of which is on view at this meeting, to be demonstrated later) the material slides down a series of spiral bands inclined towards a central column. In the case of the dirt, the friction is not overcome by velocity and centrifugal force, and it therefore remains on the bands and is discharged near the column at the base. In regard to the coal, the velocity and centrifugal force increase to such an extent that the friction is overbalanced, and the coal jumps over the band

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 69.

and falls into the chute. Many of these separators have been used in America, mostly for the treatment of anthracite. I would like to know the reason why they have not been used to the same extent for bituminous coal.

No mention has been made in the paper of the treatment of the very fine material. This has to be taken out first before going to the separators. These dry separators appear to be of no use for the treatment of any material of a less size than $\frac{1}{4}$ inch. Assuming that dry separators can be designed and used efficiently for the larger material, some other process will have to be adopted for the treatment of the fines, of which there may be a considerable quantity—such as froth flotation, perhaps.

In conclusion, I would ask Mr. Nettleton three questions, namely :—

(1) Would it be commercially impossible to separate Beeston coal, as represented in Fig. 1, from dirt which is a mixture of the typical Coal-Measure shale of Fig. 2 and black shale from the Coal-Measures of Fig. 3?

(2) As a result of the experiments from which the curves in Fig. 6 have been produced, could Mr. Nettleton say, by glancing at the figure, that there is sufficient difference in the curves of the Silkstone coal and the shale from the roof of the Silkstone Seam to enable him to effect efficient separation?

(3) As the curve for the shale from the roof of the Beeston Seam in Fig. 6 approximates the curve for the Beeston coal in Fig. 1, would it be impossible to clean the coal by this process?

Mr. Stanley Nettleton (London): It is difficult to deal at a moment's notice with such details as the point of separation of the Beeston coal from the Beeston roof, and a careful examination of friction-diagrams is desirable before I can give a definite reply to the points raised by Prof. Poole. I would like to point out, however, that there is no distinct point of division between coal and shale. In a frictional machine we find that many classes of material are being dealt with, and the more the coal becomes impure the greater is its frictional effect compared with pure coal. There is a graduated separation from extreme dirt —material with, say, 90 per cent. of ash—down to pure coal. Prof. Poole referred to the influence of time. The diagrams (Figs. 3 and 4) were inserted owing to the accidental discovery that some material which had been standing in the laboratory gave a different frictional effect from similar material when freshly broken. The difference did not appear to be due to weathering or decomposition, and possibly had some connexion with surface-tension effect. Prof. Poole is probably aware that the surface of material that has been standing for some time is often differently affected by wetting. We can break certain classes of stone and put water on to them, and the water will form up in bubbles and roll off the freshly-broken surface; but if the stone is allowed to stand for 24 hours, it will be readily wetted when water is poured upon it.

I do not quite understand Prof. Poole's reference to fine dust. The smaller the material is, the greater is the coefficient of friction. In separating-machines designed on the principles illustrated at the last meeting, it will be found that small material is thrown away with the dirt. If material of $\frac{1}{4}$ inch up to 1 inch be put through the separating-machine, the larger pieces will be thrown out on the coal side, and the smallest of the coal will have a tendency to go with the dirt. The material will have to be sized. I believe that all the machines for

mechanically separating coal from shale require that the coal shall be sized—say, in the proportion of one for the smallest to four for the largest piece—in order to get efficient working results.

Mr. J. H. W. Laverick (Tinsley Park Colliery): With regard to this method of separation, the important question is: is it an economic proposition? The test of a washer is the amount of dirt that goes away with the washed coal, and how much coal goes away with the dirt. These are problems that are exceedingly important, because 1 per cent. more or less either way means a serious monetary difference. In my opinion a machine of this type might be useful at an anthracite colliery or at a non-coking colliery. But if we were dealing with a coking colliery, we certainly would have to wash our coking slack, which may be from $\frac{3}{4}$ inch or 1 inch downwards; and it occurs to me to ask whether it is worth while having, along with the coking-slack washer, another machine of this nature for dealing with all the sizes above the coking size up to, say, cubes of 2, $2\frac{1}{2}$, or 3 inches.

The President (Lt.-Col. Harry Rhodes): I agree with Mr. Laverick in his remarks as to coking. As I said at the previous meeting, there is a field for the introduction of some process of dry separation that will do better than the boy on the picking-belt, but which need not necessarily be quite as good as the washer. If we can get something in between these two, it will be a decided step in the right direction.

Mr. H. F. Smithson (Allerton Bywater): Looking at the question purely from the economical standpoint, there is something in the dry separation of coal and dirt when one remembers the large number of boys that we have on the screens, presumably picking out stone from the coal, although they do very little in that direction. The difficulty that has always presented itself to me relates to size: it is fairly easy to clean coal above a certain size, and it is easy to wash coal above a certain size; the real problem of cleaning coal is when we get down to coal below $\frac{1}{4}$ inch. I hope to have an opportunity of taking part in the discussion at the next meeting, after we have inspected the Spiral separator which we are to see later on. I think the principle of that system and of Mr. Nettleton's is entirely the same. I have had an opportunity of studying the model of the Spiral separator, and I am impressed by it. Whether it will operate for bituminous coal in the same way that it does for anthracite remains to be seen. The greatest difficulty that I forsee in both Mr. Nettleton's and the Spiral system is in respect of coal coming out of the pit in a wet condition.

Mr. D. H. Currer Briggs (Whitwood Collieries): Some months ago, when Mr. Nettleton was carrying out some trials in the North of England, I went to examine the apparatus, taking with me some samples of Beeston coal, just as it was sized off the screens, with the dirt in it. The results obtained were quite satisfactory. We have a high percentage of dirt, as probably all collieries have that work this seam at the present time, and we put the coal through Mr. Nettleton's apparatus. We found that a large amount of pure coal was separated out in the correct manner: a certain amount of dirty coal—I mean coal with dirt actually adhering to it—went into the dirt compartment, and practically all the dirt went into the dirt compartment. I suggested to Mr. Nettleton that he should have a compartment for what I should call "middlings," or dirt and coal, which should not go into the dirt compartment, and that this new compartment should be placed between the

dirt and the coal compartments. The results of the trials were so satisfactory that we have already ordered for our colliery a small plant in accordance with Mr. Nettleton's design, but it is of a purely experimental character at present. The capacity has not yet been proved, but the plant should be working within six or eight weeks, and we hope to put about 5 tons of coal an hour through it. I think the dirt and coal which go into the "middlings" compartment will have to be taken over the plate again and re-separated. I must say that the results we had with a small apparatus with about a 4-foot or 5-foot table, which we tried at Messrs. Head, Wrightson, & Company's works, were really satisfactory. Could Mr. Nettleton alter the machine to suit different sizes of coal without necessarily altering the angle of the chute which leads the coal down to the plate? I understand that in the machine the speed of the plate which revolves is suited to the particular class of coal for which it is designed. By varying the speed of the plate, and without varying the speed of the chute, could the same apparatus be made to suit a different class or quality of coal?

Mr. Nettleton: In reply to Mr. Briggs, the adjustment to size can be done either by altering the speed of the rotating disc or by altering the delivery-chute. The delivery-chute regulation gives a greater control than the alteration of speed, but some regulation can be got by altering the moving disc.

The further discussion of the paper was adjourned.

SPIRAL SEPARATOR FOR THE DRY SEPARATION OF DIRT FROM COAL.

Mr. J. L. Wood (Newcastle-upon-Tyne) gave a demonstration of this separator, of which the following is a brief description:—

The separator consists of a central post with a series of spiral threads inclined towards the centre, down which the coal and stone slide; the coal maintains a fixed path so long as the friction of the coal on the stone thread and the centrifugal force balance. As the velocity increases and overcomes the friction, the coal moves to the outer edge of the stone thread, falling over the edge into the flanged coal thread, and is carried off. The stone, which has a higher coefficient of friction, follows the regular path, and, at the bottom, goes into the refuse pocket.

Spiral separators are stationary, and require no power to operate them other than gravity, frictional resistance, and centrifugal forces. Gravity carries the material down the spiral separating threads. The peculiar formation and widths of the separating jackets, with half covers, increase or decrease the frictional resistance of stone and coal, causing each to run in separate paths.

Between coal and metal there is less attraction than between the impurities (which are metallic in character) and metal. The coal being lighter, and having less affinity for metal, naturally flies over the edge of the stone thread into the coal thread, down which it travels into the hopper or wagons underneath. Impurities such as stone, bastard coal, etc., have greater weight and greater attractions for metal, and thus stay on the stone thread until they get to the bottom.

It is interesting to watch the behaviour of these three elements as they move down the spiral. The coal gingerly hops over the edge into the coal thread and then shoots down into the hopper or wagon underneath.

The stone, a rather sluggish moving body, goes plodding along down the spiral, always hugging the post. The bastard coal is forever undecided whether to follow its half-brother the stone, or its half-brother the coal; finally, it decides to do neither, but takes a course almost exactly between the two. Thus the bastard coal slides down quietly and easily on the outer edge of the stone thread, and, if desired, is led away for burning in the furnace.

Each separator, when dealing with sized bituminous coal, is capable of handling from 8 to 12 tons per hour. An intermittent feed, such as direct from a shaker-conveyor or screen, not exceeding the above-mentioned capacity, is an important item.

Sized coal from 6 inches to $\frac{1}{4}$ inch can be dealt with—for example, sizes approximating the following :—

Through 6 inches and over 4 inches.
,, 4 ,, ,, ,, $2\frac{1}{2}$,,
,, $2\frac{1}{2}$,, ,, ,, $1\frac{1}{2}$,,
,, $1\frac{1}{2}$,, ,, ,, $\frac{3}{4}$,,
,, $\frac{3}{4}$ inch ,, ,, $\frac{1}{4}$ inch.

Each separator is built to suit the particular size and grade of coal at each colliery.

The separator is not an experiment, but has been tried and proved, over a period of twenty years in America, to be a most efficient and economical method of separating stone from coal. Over 3,000 of these separators are now in use.

Mr. J. L. Wood : The coal which gives the best results when put over the separator is first of all sized, and the dust screened off. The smallest size with which the apparatus works really well is down to $\frac{1}{4}$ inch, and the largest about 6 inches, although it will deal with material a little larger.

Mr. F. E. Pardee (Hazleton, Pa.) : The separator was originally conceived in 1898 in the anthracite coalfields of the United States, so that it has been working for more than twenty years. As soon as it got a foothold in the anthracite field, the apparatus was developed for the bituminous coalfields. Many people are under the impression that the apparatus is for use purely for anthracite coal, but this is not so. In many cases it is just as efficient for bituminous coal as for anthracite, and sometimes even more so. It has been working on bituminous coal in America for eight or ten years. So far as economy is concerned, the Spiral separator is, I believe, as economical as any machine on the market. It requires no power to operate. The coal has, of course, to be elevated to a sufficient height to allow it to go down the spiral; but after it once gets on to the spiral, no power whatever is required. Different spirals are built for the different sizes of coal, and the model on view can be used only for about $\frac{1}{2}$-inch material. The anthracite and bituminous spirals are quite different, although approximately the same in general appearance.

Major G. S. Nelson then gave a demonstration with the model, passing through it several kinds of bituminous coal from the Yorkshire Coalfield.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

ANNUAL GENERAL MEETING,

HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS, 5, JOHN DALTON STREET, MANCHESTER, OCTOBER 11TH, 1921.

Mr. VINCENT BRAMALL, RETIRING-PRESIDENT, IN THE CHAIR.

DEATH OF SIR WILLIAM GARFORTH, LL.D.

The RETIRING-PRESIDENT: Before commencing the meeting I wish to move a vote of condolence with the family of the late Sir William Garforth, who died on October 1st. Sir William was elected a member of this Society in 1873, and I believe was our oldest member. He always took the greatest interest in the affairs of the Society and in all matters connected with improvements in mining and the welfare of the men engaged in that industry.

Mr. SYDNEY A. SMITH (Manchester): In seconding the resolution, I would like to add my tribute to the memory of Sir William Garforth, who was one of my oldest and best personal friends, and with whom I was associated intimately in business matters for a long period of years.

The resolution was passed, the members rising in their places.

ABSTRACT OF ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

Forty new members have been elected during the year, namely, three Members, sixteen Associate Members, fourteen Associates, and seven Students. Four members have been transferred, namely, one Student to the class of Associate, one Student to the class of Associate Member, and one Associate and one Associate Member to the class of Member. There have been eleven withdrawals of members by resignation and other causes. The total membership now stands at 469, an increase of 27 on the previous year.

The Council regrets to record the death of two members, namely, Sir William Scott Barrett and Mr. Benjamin P. Griffiths. Sir William Barrett was a Past-President of the Society, and both as President and as a Member of Council he rendered splendid service not only to the Society but to the mining industry. The Council extend their sympathy and condolence to the relatives of the deceased.

Twelve meetings of the Council, eight Ordinary Meetings, and the Annual General Meeting have been held during the session. Nine papers have been read, and the thanks of the Society were tendered to the respective authors.

On the motion of Mr. W. Pickup, seconded by Mr. A. J. A. Orchard, the Annual Report and Accounts were unanimously approved.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY: ABSTRACT OF BALANCE-SHEET, JULY 31ST, 1921.

LIABILITIES.			Year 1920-1921 £ s. d.	Year 1919-1920 £ s. d.
Sundry creditors			62 18 0	13 13 6
Subscriptions received in advance for the year 1921-1922			6 6 0	43 1 0
Williams Deacons Bank, Limited			275 14 9	244 1 11
Accumulated fund:—Balance as at July 31st, 1920	£ s. d. 1,739 3 6			
Add Excess of income over expenditure	34 11 9			
	1,773 15 3			
Less Loss on realization of Birkenhead Railway 4-per-cent Consolidated Preference Stock (£251 11s. 4d.) and on Lancashire & Yorkshire 3-per-cent. Consoliated Preference Stock (£228 15s. 5d.)	480 6 9			
			1,293 8 6	1,739 3 6
			£1,638 7 3	£2,039 19 11

ASSETS.			Year 1920-1921 £ s. d.	Year 1919-1920 £ s. d.
Investments—	£ s. d.			
£600 Birkenhead Railway 4-per-cent. Consolidated Preference Stock at £100½	603 0 0			
£733 Lancashire & Yorkshire Railway 3-per-Cent. Consolidated Pre-Preference Stock at £72	527 15 2			
			0 0 0	1,130 15 2
(The value of the above Stock on July 31st, 1920, was £682.)				
Queen's Buildings (Manchester), Limited: 1,000 shares at £1 each, fully paid ...			1,000 0 0	300 0 0
Library and furniture			543 16 0	543 16 0
Unexpired portion of periodical payment ...			1 8 4	1 5 10
Cash in hand			3 5 11	1 18 0
Arrears of subscriptions, *less* amounts to be paid to The Institution of Mining Engineers			89 17 0	52 11 0
Sundry debtors			0 0 0	9 13 11
			£1,638 7 3	£2,039 19 11

INCOME-AND-EXPENDITURE ACCOUNT FOR THE YEAR ENDED JULY 31ST, 1921.

EXPENDITURE.	Year 1920-1921 £ s. d.	Year 1919-1920 £ s. d.
To The Institution of Mining Engineers:—		
Calls paid	498 15 0	396 0 0
Estimated amount owing for calls ...	84 4 0	57 1 0
,, Salaries, reporting, travelling expenses, auditing, etc.	285 13 9	187 18 0
,, Rent and lighting	104 14 11	86 1 1
,, Printing and stationery and miscellaneous expenses	183 19 3½	126 16 5½
,, Postages and telegrams	26 8 1½	25 2 9½
,, Institution annual dinner	65 16 4	0 0 0
,, Publications, authors' copies and exchanges, etc.	8 6 9	15 15 10
,, Excess of income over expenditure ...	34 11 9	71 2 10
	£1,292 9 11	£965 18 0

INCOME.	Year 1920-1921 £ s. d.	Year 1919-1920 £ s. d.
By Subscriptions	1,126 13 0	780 17 0
,, Arrears of subscriptions (estimated) ...	149 6 0	92 7 0
,, Interest on investments (*less* tax), etc. ...	0 3 2	74 10 0
,, Sales of *Transactions* and authors' copies	16 7 9	18 4 0
	£1,292 9 11	£965 18 0

Mr. Sydney A. Smith was unanimously elected President for the ensuing year.

The President (Mr. Sydney A. Smith): I thank you for the honour you have conferred upon me in electing me President, and especially for the kind way in which the proposition has been made.

Mr William Pickup proposed and Mr. A. J. A. Orchard seconded a hearty vote of thanks to Mr. Vincent Bramall, the Retiring-President, for his services in the chair during the past twelve months, and the resolution was passed unanimously.

Mr. Vincent Bramall: I thank you sincerely for the generous way in which you have recognized my services.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were elected:—

Associate Members—

Mr. Esau Protheroe Anderson, 17, Pleasant View, Llanhilleth, Newport, Mon.

Mr. Owen O. Roberts, "Eryri," Llanrug, Carnarvonshire.

Mr. Evan Owen Thomas, "Pontyrhun," Troedyrhiw, Glam.

Associates—

Mr. John Thomas Hughes, 333, Tyldesley Road, Hindsford, Atherton, Manchester.

Mr. William Martin, 69, Leigh Road, Atherton, Manchester.

Mr. Walter Stanley Tong, 25, Columbia Road, Bolton.

A CONTRIBUTION TO THE STUDY OF FUSAIN.

By F. S. SINNATT, M.B.E., M.Sc. (Tech.), F.I.C.

A considerable part of the work contained in this paper has been carried out under the auspices of the Lancashire and Cheshire Coal Research Association.

Of the four ingredients of banded bituminous coal described by Dr. Marie Stopes (*Procs. Roy. Soc.*, 1919, Vol. XC., page 470) the most clearly marked is fusain (mother-of-coal, suddy parting). Stopes and Wheeler in their comprehensive monograph on "The Constitution of Coal" (*Department of Scientific and Industrial Research*, 1918) deal with the literature of the subject in a very complete form, and it is not proposed to repeat the matter in this paper. Tideswell and Wheeler (*Journ. Chem. Soc.*, 1919, Vol. CXV., page 619) undertook an examination of the properties of fusain and the other constituents of coal especially from the point of view of the amount of substance extracted by different solvents and the gaseous products obtained on carbonization. They showed that fusain was entirely different in properties from the other three constituents. In two valuable contributions to the subject, R. Lessing (*Journ. Chem. Soc.*, 1920, Vol. CXVII., Part 1, pages 247 and 256) examined the results of carbonizing fusain, and also compared the composition of the inorganic constituents with those obtained from vitrain, clarain, and durain. In a bulletin on "Coal-dust and Fusain" (*Lanc. Ches. Coal Res. Ass.*, Bull. No. 5) Bailey, Stern, and the author pointed out that the fusains found in different coals possessed different chemical compositions, and that, owing to the fact that coal fractures at the layers of fusain, the dust carried away from coal usually contained a considerably higher percentage of fusain than is present in the original coal. Certain figures from that bulletin are repeated in this paper in order to lend to the description a more logical sequence.

In the evidence quoted in the report on the "Spontaneous Combustion of Coal in Mines"* it was shown that heaps of fusain may be ignited by means of a match, and will then undergo a slow combustion, which is not accompanied by flame or smoke and only by the faintest odour or gob-stink. The combustion of coal and fusain has been examined in greater detail, but the results are not in a form for publication at present.

The cause of the ready combustion of fusain may be associated with two characteristics: the first is the extreme degree of fineness of the material, and the second its highly porous texture. Certain preliminary experiments will be quoted in this paper in order to indicate the manner in which fusain will burn.

The amount of fusain in coal is comparatively small, but Hickling ("Contributions to the Micro-petrology of Coal," *Trans. Inst. M. E.*, 1916-1917, Vol. LIII., page 137) states that mother-of-coal or fusain may make up 5 per cent. or possibly more of a seam, although it is generally much less. He adds (page 150) that "this material presents us with the one clear case in which the present substance would appear to be the result

* See *Minutes of Evidence*, 1921.

of direct alteration off the original plant-tissues, without the addition of extraneous material."

Fusain occurs in Lancashire coal in two main forms, namely :—

(1) As local aggregations which attain as great a weight as 4 pounds.

(2) In very thin layers disseminated throughout the whole mass of the coal.

These two types of fusain exhibit no marked difference in structure when examined under the microscope. The fusain which occurs in thin layers is of greater importance than the larger masses, as it forms by far the greater total amount.

Both types of fusain have been examined, and the following results have been obtained from two solid aggregations. The first piece of fusain was found in the Peacock Mine, and weighed $3\frac{3}{4}$ pounds. I am indebted to Mr. H. J. Whitehead, of the Abram Coal Company, for preserving this specimen and presenting it to me. The lump was cut into two pieces, and one portion was crushed between the fingers and sieved fractionally as under :—

	Per cent.
Remaining on 1/60-mesh sieve	42·5
,, 1/60 to 1/90-mesh sieve	22·5
,, through 1/90 ,, ,, ...	35·0

The above fractions were analysed, with the results shown in Table I.

TABLE I.—ANALYSIS OF FUSAIN SEPARATED BY SIEVING.

Description.	Left on 1/60-mesh sieve.	Through 1/60-mesh sieve.	Through 1/90-mesh sieve.	Sample of coal.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	1·50	0·89	0·63	2·76
Ash	25·99	15·23	11·65	8·06
Volatile matter	15·82	13·09	10·41	39·8
Volatile matter on ash-and-moisture-free basis	19·75	14·54	11·15	37·04
Coke	84·18	86·91	89·59	60·2
Fixed carbon	58·19	71·68	77·94	52·1

A specimen of each of the above fractions was incinerated at 800° Cent., and the residual ash analysed :—

Description.	Left on 1/60-mesh sieve.	Through 1/60-mesh sieve.	Through 1/90-mesh sieve.
	Per cent.	Per cent.	Per cent.
Silica	47·71	49·83	51·78
Iron oxide	28·27	24·79	20·84
Alumina	14·05	14·36	15·32
Calcium oxide	5·09	5·02	4·13
Magnesium oxide	2·03	1·85	1·56
Alkalis and sulphur trioxide	2·85	4·15	6·37
	100·00	100·00	100·00

The above analyses show that the inorganic matter present in the fusain in a fine state of division differs only in a small degree from that present in the coarser material, despite the fact that two types of fusain possess an entirely different composition. As will be indicated later, fusain will undergo slow combustion much more readily than coal-dust, and the explanation of this it was thought might be found in the influence that the inorganic matter might have upon this combustion. From

the above analyses, however, it would seem that the differences in the composition of the ash are not of such a degree as to warrant such a theory.

The values shown in Table II. were obtained from a specimen, found in the Ravine Mine, which weighed about ¼ pound.

TABLE II.—EXAMINATION OF AGGREGATION OF FUSAIN.

	Per cent.
Remaining on a 1/30-mesh sieve	25·4
Between 1/30 and 1/60 ,, ,, ...	33·6
,, 1/60 and 1/90 ,, ,, ...	35·3
Passing through a 1/90 ,, ,, ...	5·7

Upon analysis the fractions gave the following results:—

Description.	Coal remaining on a 1/30-mesh sieve.	Fusain through 1/30 to 1/60-mesh sieve.	Fusain through 1/60 to 1/90-mesh sieve.	Fusain through a 1/90-mesh sieve
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	1·50	0·90	0·55	0·70
Ash	17·50	10·00	5·89	6·70
Volatile matter	24·20	16·24	11·97	11·73
Volatile organic matter	22·70	15·34	11·42	11·03
Coke	75·80	83·76	88·03	88·27
Fixed carbon	58·30	73·76	82·14	81·57
Sulphur	5·96	3·54	2·34	2·82
Colour of ash	maroon	maroon	brown	light maroon
Nature of coke	dull, grey, very hard, a compact flat button	dull, grey, incoherent	dull, grey, incoherent	dull, grey, incoherent
Iron in ash	31·6	30·3	33·2	35·0

The remarkable feature of this piece of fusain was the presence of a high percentage of sulphur compared with that found in the coal-seam in which it occurred. It will be remarked that the coarse material contains a higher percentage of sulphur than the fine material, but both differ in composition from the pulverulent variety of fusain which occurs in the same seam (see Table III.).

TABLE III.—CHEMICAL ANALYSES OF FUSAINS (PULVERULENT VARIETY).

Description.	Upper King Coal.	Mountain Mine.	Hell Hole Mine.	Arley Mine.	Ravine Mine.	Yard Mine, Atherton.	Wigan Six Feet.
	Per cent.	Per cent	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	1·23	0·45	0·70	1·40	1·50	1·70	1·40
Ash	10·86	7·14	6·71	4·72	11·22	8·55	5·40
Volatile matter	19·90	9·52	15·97	13·21	15·80	11·23	16·02
Volatile organic matter	18·67	8·87	15·27	11·81	14·30	9·50	14·62
Coke	80·10	90·68	84·03	86·79	84·20	88·77	84·00
Fixed carbon	69·24	83·54	77·32	82·07	72·98	80·22	78·60
			ULTIMATE ANALYSIS.				
Carbon	77·30	—	83·26	84·63	76·85	84·60	82·65
Hydrogen	3·82	—	3·27	3·24	3·47	2·70	3·30
Nitrogen	0·79	—	0·84	0·76	0·73	0·89	0·71
Sulphur	1·62	—	3·36	2·11	2·85	1·30	1·10
Ash	11·00	—	6·76	4·79	11·41	8·70	5·50
Oxygen (by difference)	5·47	—	2·51	4·47	4·69	11·81	6·74
Calorific value, in B.Th.Us. per pound	13,423	13,968	14,015	14,700	12,880	13,890	13,760

It was noticed that as the material (Table II.) was sieved the finer fractions assumed a more intense black colour than the coarser material. It will be seen that the material which passed through a 1/60-mesh sieve differed only slightly in composition from that which passed through a 1/90-mesh sieve; in fact, it would appear from the figures that the fusain which passed through a 1/60-mesh sieve may be considered as practically constant in composition. Nevertheless, the coarser material always differs in composition from the coal-seam in which the material occurs, and consequently it must be assumed that the composition of fusain varies with the degree of fineness until the material is of such a type that it will pass through a 1/60-mesh sieve.

Samples of fusain were collected from a number of the seams in the Lancashire Coalfield, and the chemical analyses are given in Table III.

The following are the analyses of the coal from which the above samples of fusain were obtained :—

Chemical Analyses of Coals.

Description.	Upper King Coal.	Mountain Mine.	Hell Hole Mine.	Arley Mine.	Ravine Mine.	Yard Mine, Atherton.	Wigan Six Feet.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	2·16	2·73	1·94	1·92	2·42	3·01	6·00
Ash	3·72	3·52	2·67	3·23	4·05	2·97	4·42
Volatile matter	40·19	26·46	35·00	35·34	36·56	33·22	39·12
Volatile organic matter	38·03	23·73	33·06	33·42	34·14	30·21	33·12
Coke	59·81	73·54	65·00	64·66	63·44	66·78	60·88
Fixed carbon	66·09	70·62	62·33	61·43	59·39	63·81	56·46
Ultimate Analysis.							
Carbon	76·96	81·94	82·25	83·32	78·42	—	—
Hydrogen	5·01	5·28	5·34	5·51	5·24	—	—
Nitrogen	1·62	1·16	1·62	1·54	1·50	1·53	1·42
Sulphur	1·98	1·61	1·02	1·45	2·28	1·60	1·65
Ash	3·80	3·62	2·73	3·29	4·15	—	—
Oxygen (by difference)	10·63	6·39	7·05	5·89	8·41	—	—
Calorific value, in B.Th.Us. per pound	14,050	15,040	14,589	14,740	14,360	14,430	14,510

It may be pointed out that the percentages of volatile matter and oxygen in fusain are lower than are present in the associated coal.

Table IV.—Analyses of Ash of Fractions of Fusain.

Description.	Remaining on 1/30-mesh sieve.	Through 1/60-mesh sieve.	Through 1/90-mesh sieve.
	Per cent.	Per cent.	Per cent.
Silica	24·19	31·55	37·60
Iron oxide	20·15	25·30	30·33
Alumina	39·15	24·55	13·12
Calcium oxide	8·06	7·48	4·78
Magnesium oxide	1·97	2·53	2·80
Sulphur trioxide	5·52	3·64	2·84
Alkalies, etc.	0·96	4·95	8·63
Totals	100·00	100·00	100·10

The pulverulent variety of fusain occurring in Arley coal is especially homogeneous in texture, but it was considered desirable to place on record the analyses of the ash of the coarse material and the fine material. It may be remarked that over 85 per cent. of this material would pass

through a 1/90-mesh sieve, of which about 80 per cent. was so fine as to pass through a 1/200-mesh sieve; no further evidence is available of the ultimate fineness of the material.

The analytical values obtained from the analysis of the ash of the fine and coarser material are recorded in Table IV.

In order to gain an impression of the occurrence of fusain on surfaces of coal, and, in addition, to confirm experimentally the fact that coal breaks preferentially at the layers of fusain, experiments were carried out upon a number of Lancashire seams under the following conditions:—

About one hundred lumps were picked indiscriminately from masses of coal which had been broken by simple fracture. The determination on the Trencherbone sample was carried out on coal as it was delivered from a cart for household purposes; other determinations were carried out on the belt during hand-picking; and in another case about 1 cwt. of large lumps were allowed to fall, and thus to fracture naturally. The surfaces parallel to the bedding-plane were then examined for fusain, and the results are given in Table V.

TABLE V.—PERCENTAGE OF SURFACES PARALLEL TO THE BEDDING-PLANE COVERED WITH FUSAIN.

	Per cent.
Trencherbone	90
Wigan Five Feet	80
Wigan Yard	90
Barnsley Thick Bed (Tops)	60

Table V. shows that if the vertical faces of the coal are ignored, from 60 to 90 per cent. of the total surface of the coal exposed to the air in the mine may be covered with fusain. If, on the other hand, the assumption is made that coal fractures into perfect cubes, 33 per cent. of the total surfaces exposed to the air are parallel to the bedding-plane; it follows, therefore, that from 20 to 30 per cent. of the maximum surface of the coal may be covered with fusain, and the dust carried away from the coal should contain a higher proportion of fusain than the original coal. In view of the fact that the face is frequently highly polished and sometimes covered with a film of inorganic matter, the dust produced is comparatively small, and when once the coal has fallen the main sources of dust are the surfaces parallel to the bedding-plane.

TABLE VI.—ARLEY COAL AND ARLEY FUSAIN.

Coal.	Fusain.	Volatile matter of mixture on moisture-and-ash-free basis.
Per cent.	Per cent.	Per cent.
100	0	36·59
98·4	1·6	35·30
80	20	30·11
60	40	25·71
40	60	21·73
20	80	17·66
0	100	13·59
	YARD COAL AND YARD FUSAIN.	
100	0	35·70
97·9	2·1	33·22
80	20	28·94
60	40	24·21
40	60	19·94
20	80	16·16
0	100	11·92

It was necessary to attempt to devise some method for the determination of fusain in dust, and the following process was found to yield approximate results :—

The percentage of moisture, ash, and volatile matter in a sample of pure coal and fusain was determined. The dust suspected of containing fusain was examined for the same values under exactly parallel conditions. The determination of the volatile matter was carried out in Lessing's apparatus at a constant temperature. The volatile organic matter in the dust was then calculated on an ash-and-moisture-free basis. It was then possible to calculate the percentage of fusain which had brought about the reduction of the volatile matter found in the dust. In order to confirm the method, artificial mixtures of coal and fusain were prepared, and the moisture, ash, and volatile matter present were estimated. Table VI. records the results obtained in the two typical cases.

Table VII.—Fusain Present in Certain Lancashire Seams.

Size.	Coal.	Ash.	Volatile matter.	Moisture.	Volatile organic matter on ash-free basis.	Fusain.	Fusain in coal.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Wigan Four Foot Seam.							
1/10 to 1/90	80	7·4	38·5	2·3	40·1	0·0	0·0
1/90 to 1/200	12	8·1	37·33	2·0	39·26	0·0	0·0
Through 1/200	8	9·0	30·50	2·3	31·81	34·4	2·8
						Percentage of fusain in coal	2·8
Arley Coal.							
1/10 to 1/90	81	2·95	36·85	2·1	36·59	0·0	0·0
1/90 to 1/200	13	3·50	35·20	2·1	35·05	6·3	0·8
Through 1/200	6	4·30	33·17	2·0	33·28	13·5	0·8
						Percentage of fusain in coal	1·6
Wigan Yard Coal.							
1/10 to 1/90	84·0	1·84	41·32	2·0	40·89	0·0	0·0
1/90 to 1/200	7·8	2·07	40·20	2·0	39·83	4·3	0·34
Through 1/200	8·2	3·18	35·77	2·0	35·61	21·2	1·74
						Percentage of fusain in coal	2·1
King Coal.							
1/10 to 1/90	73	10·28	33·1	2·0	35·5	0·0	0·0
1/90 to 1/200	11	7·80	33·2	1·7	34·6	4·6	0·5
Through 1/200	16	9·98	31·5	2·0	32·8	13·8	2·2
						Percentage of fusain in coal	2·7
Mountain Mine Coal.							
1/10 to 1/90	71·5	5·46	27·62	1·5	27·5	0·0	0·0
1/90 to 1/200	15·0	5·32	27·81	1·5	27·6	0·0	0·0
Through 1/200	13·5	4·48	26·80	2·0	26·5	5·6	0·8
						Percentage of fusain in coal	0·8

Although the results recorded in Table VI. agree only roughly with the calculated values, the principle has been applied to the approximate determination of fusain in coal. An average sample of clean coal was obtained and crushed to a coarse powder so that it would pass through a sieve of 1/10-mesh, the assumption being that bands of fusain are seldom closer together than $\frac{1}{20}$-inch. The material was then systematically

pressed between the fingers, in order to pulverize and separate the fusain, and 100 grammes were taken and sieved first through a 1/90-mesh sieve and then through a 1/200-mesh sieve. The two first fractions were again pressed between the fingers, and re-sieved. The resulting powders were then analysed under exactly identical conditions, with the results shown in Table VII.

From the above values it will be seen that any process in the purification of coal which tends to remove the fusain from it will increase the percentage of volatile matter actually present in the coal. The removal of 1 to 3 per cent. of fusain has a distinct influence on the amount of volatile matter evolved when the coal is heated. Washed and screened small coals are, therefore, richer in volatile matter than are lump coals. The presence or absence of fusain is of distinct interest to the analyst, as it modifies the results obtained in the analysis of coal, especially in the determination of the volatile matter.

It is recognized that the results recorded in Table VII. can only hope to be of an approximate nature, but in lieu of a better method it appears desirable to place the values on record as indicating one process which may lead to a knowledge of the percentage of fusain in the coal-seam.

Some confirmation of the values has been obtained by treating the pulverized coal by froth flotation. The fusain may be sharply separated by flotation partly without the addition of reagents.

If the above results may be accepted as representing the amount of fusain present in an average sample of the seam, it will be gathered that during ordinary combustion the constituent is relatively unimportant. In view of the fact that coal fractures preferentially at the layer of fusain, the dust carried away from coal as mine-dust and the dust formed during the screening, washing, or transport of coal will contain a higher percentage of fusain that the coal as a whole. In order to elaborate the arguments of this paper, the results in Table VIII. are quoted from Bulletin No. 5, " Fusain and Coal-dust " (*Lanc. and Ches. Coal Res. Ass.*), and show the amount of fusain found in the dust from a mine. The dust was collected close to the coal-face.

Table VIII.—Amount of Fusain found in Mine-dust.

Description.	Analysis of mine dust.			
	Sample No. 1.	Sample No. 2.	Sample No. 3.	Sample No. 4.
	Per cent.	Per cent.	Per cent.	Per cent.
Moisture	1·3	0·9	1·4	1·4
Ash	28·7	10·1	23·2	19·2
Volatile matter	21·8	22·5	25·0	25·4
Volatile organic matter	20·5	21·6	23·6	24·0
Coke	78·2	77·5	75·0	74·6
Fixed carbon	49·5	67·4	51·8	55·4
Fusain present	25	47	16	21

In a recent discussion Mr. J. Ivon Graham stated that he had been unable to confirm these results from the Yorkshire pits, but in view of the fact that the amount is so pronounced in the above determinations, it is desirable to assume that the mine-dust does contain fusain, and it appears to be of distinct interest to have the amount determined.

A dust which was examined with considerable interest was one from a dust-collector in which the dust from a belt picking-room was separated. The results are quoted from the same bulletin, and are given in Table IX.

Table IX.—Examination of Dust from Dust-collector.

Average Sample. Approximate Analysis.	Per cent.
Moisture	1·2
Ash	9·1
Volatile matter	22·6
Volatile organic matter	21·4
Coke	77·4
Fixed carbon	68·3
Fusain	49

Quantitive Sieving Test of the Dust Showed.

Above 1/30-mesh sieve	0·0
1/30 to 1/60 ,,	1·5
1/60 to 1/90 ,,	3·0
1/90 to 1/200 ,,	15·5
Through 1/200 ,,	80·0

Analysis of Products.

Mesh of sieve, 1/30 *to* 1/90.	Per cent.	*Mesh of sieve, through* 1/90.	Per cent.
Moisture	2·1	Moisture	1·2
Ash	7·0	Ash	9·6
Volatile matter	31·3	Volatile matter	21·4
Volatile organic matter	29·2	Volatile organic matter	20·2
Coke	68·7	Coke	78·6
Fixed carbon	61·7	Fixed carbon	69·0
Fusain	13	Fusain	54

The extreme fineness of the material should be emphasized, and the amount of fusain present is surprising.

No experiments appear to be available as to the relative explosive properties of fusain, dust, and coal-dust in air, but in view of the fact that this property of dust is frequently associated with the percentage of volatile matter in the material, and that dust containing fusain contains a much lower percentage of volatile matter than coal-dust, it would follow that the presence of fusain in coal-dust would render it less explosive than ordinary coal-dust. On this assumption the presence of fusain in mine-dust tends to make the dust less dangerous. On the reverse side, however, is the fact that fusain pulverizes more readily than coal, and the dust is in a much finer state of division than coal-dust. In addition, fusain possesses a highly-porous texture; this property lends to the substance increased chemical activity, and, as will be shown later, there appears to be little doubt that under certain conditions fusain reacts very readily with the oxygen of the air.

As no means are at my disposal by which the explosive properties of fusain-dust suspended in air may be compared with coal-dust, attention may be called to the work of Dr. J. Harger (*Trans. Inst. M. E.*, 1912, Vol. XLIII., page 132), who compared the degree of ignition of coal-dusts derived from various sources. Thus he compared dusts obtained from coal-screens and haulage-ways with fresh coal-dust. He found that dust made by grinding fresh coal would explode, whereas that from the screens and collected from the timber in the haulage-ways could not be made to explode. In the course of his paper (page 145) he gave the results shown in Table X.

TABLE X.—COMPARISION OF DEGREE OF IGNITION OF COAL-DUST DERIVED FROM VARIOUS SOURCES.

	Percentage of ash.	Degree of explosion (normal air).
Arley Mine coal (ground)	—	Full.
Arley Mine dust (*a*)	7·7	None.
Do. (*b*)	17·1	,,
Do. (*c*)	25·9	,,
Mountain Mine coal	—	Full.
Mine-dust	11·0	None.
Screen-dust	—	,,
Barnsley Seam coal-dust	1·3	Full.
Screen-dust	10·4	None.
Dust from timber in haulage-ways (*a*)	19·5	,,
Dust ,, ,, ,, (*b*)	33·0	,,

The above results were explained by Harger on the assumption that the dust contained a relatively high percentage of ash. In view of the experiments described in the present paper, it would appear that Harger's results could also be explained by assuming that the dusts with which he was working contained a considerable percentage of fusain. The fact that a number of his experiments were carried out on Arley Mine dust indicates that he was probably working with dust containing fusain. His results are of importance, as they indicate that mine-dust which presumably contains fusain is evidently not nearly so liable to form explosive mixtures as pure coal-dust, and it emphasizes the necessity for an examination of the explosive character of fusain from all the common coals and, further, the determination of the constituent in the mine-dusts.

Presence of Fusain in Slurry or Dant.—It is well known that slurry or dant contains fusain, but it appears to be of interest to place on record the percentage present in a typical slurry, and the following values were obtained by the examination of a tankful of slurry. A section was obtained from the top to the bottom of the material, which was 4 feet deep. Each 6 inches of material was kept quite separate and analysed. The results are contained in Table XI.

TABLE XI.—PERCENTAGE OF FUSAIN IN SLURRY OR DANT FROM WASHERY.

Slurry.	Moisture.	Ash.	Volatile organic matter.	Fusain.
Depth, in inches.	Per cent.	Per cent.	Per cent.	Per cent.
0 to 6	1·9	6·0	21·3	52
6 ,, 12	2·0	10·9	26·1	22
12 ,, 18	7·7	10·8	24·0	24
18 ,, 24	6·8	10·6	25·4	19
24 ,, 30	3·4	9·6	27·5	15
30 ,, 36	5·3	11·2	26·4	15
36 ,, 42	7·1	13·4	24·0	21
42 ,, 48	8·3	13·3	21·9	31

It will be noticed that the average amount of fusain in the tank is about 25 per cent., but that the top 6 inches contains over 50 per cent. Examination of the coke obtained from each of these layers of material showed that the caking value of the coal was much reduced, and the top 6 inches was found to yield an incoherent coke. In other words, the agglutinating power of the coal had been completely destroyed. The percentage of ash in this particular layer is only 6; consequently it would appear that the mixture of the coal with about 50 per cent. of fusain destroyed the caking power of the former. During the treatment of the

coal with water in a washery, or while it is undergoing any strong vibration, the fusain becomes pulverized to a very fine state of division, with the result that a very small proportion of it will lead to the destruction of the caking power of the coal. Thus it has been found that if, say, Arley coal is mixed with fusain which will pass through a 1/60-mesh sieve and be caught upon a 1/90-mesh sieve, it requires about eight proportions of fusain to destroy the caking power. This result is in agreement with those obtained by mixing coal with inert matter of varying degrees of fineness, and it was shown that Arley Mine coal required the following proportions (Sinnatt and Grounds, *Journ. Soc. Chem. Indus.*, 1921, Vol. XL., pages 1T to 4T):—

Arley Coal.

Degree of fineness of pulverized carbon	1/180 to 1/200	1/120 to 1/800	1/90 to 1/120	1/60 to 1/90	1/30 to 1/60	1/10 to 1/30
Proportion of electrode carbon to destroy caking power	1·2	1·7	4·5	8·0	20·0	25·0

It will be gathered from the above that the presence of a small proportion of finely-divided fusain may have a considerable adverse influence upon the coke obtained from coal. It also indicates that where slurry or dant is being mixed with coal in order to make use of the material, it should not be possible for the slurry to collect in any particular part, but it must be distributed evenly throughout the whole mass of the coal. From the point of view of collieries where it is the practice to burn the slurry in their ordinary stoke-holes, it will be seen that practically non-coking slurry may be produced from coal which is highly coking. If considerable draught is used to deal with the coal normally, a great deal of dust may be drawn up the chimney when the dant or slurry of low caking power is being burned.

During the study of the white partings in coal (*Journ. Soc. Chem. Indus.*, January 15th, 1921, Vol. XL., No. 1, pages 1T to 4T), and whilst examining the various ways in which fusain occurred in coal, it was observed that the white partings frequently terminated at a band of fusain, especially if the layer of fusain was of greater thickness than a mere film. This observation led to an enquiry as to whether the occurrence was a general one, and although the fact could not be completely established, the phenomenon was found to be general in a number of seams, but especially in the Mountain Mine Seam. In this particular case a thick sheet of ankerite terminated at a band of fusain, and reappeared some distance horizontally along the fusain. This observation, to which no reference in the literature on the subject can be traced, led to an experiment the object of which was to determine the rate at which liquids would flow through a band of fusain.

A piece of freshly-mined coal, chosen for the fact that it contained a single and firm layer of fusain $\frac{1}{8}$ inch in thickness, was taken, and upon it a perfectly flat surface was ground. To the surface a small glass cylindrical cell, $\frac{1}{2}$ inch in internal diameter and $\frac{1}{4}$ inch high, was cemented by means of "Duroprene," which is quite insoluble and impervious to water.

The band of fusain passed directly across the small cell, which was now filled with a saturated solution of sodium chloride (common salt) for 40 hours. Sodium chloride was chosen as being a typical salt and representative of the general class of such compounds. At the end of

this period the cell was removed, and the coal carefully split open at the band of fusain. The fusain was then cut into four horizontal sections, ½ inch apart and parallel to the plane on which the cell was fixed. Each separate ½ inch of material was removed over exactly the same area of surface. The amount of sodium chloride was then determined at the successive distances, and the results are seen in Table XII.

TABLE XII.—DEGREE TO WHICH A SOLUTION OF SODIUM CHLORIDE WILL FLOW THROUGH A BAND OF FUSAIN.

Position of fusain.	Percentage of sodium chloride found.
(1) From surface to ½ inch deep	8·40
(2) „ ½ inch to 1 „	5·22
(3) „ 1 „ 1½ „	1·78
(4) „ 1½ „ 2 „	0·51
(5) Coal adjacent to No. 1 section—*i.e.*, surface to ½ inch deep	0·16

The experiment proved conclusively that the solution containing the salt passed into the fusain at a considerable rate. There is no doubt that with an increase of time further quantities of liquid would have passed into the band of fusain.

The above experiment was devised for a second reason, namely, to attempt to explain an observation made by Mr. Whitehead of the Abram Coal Company upon the fusain occurring in the Arley Mine. One of the bands of fusain in the Arley Mine, about ⅛ inch in thickness, is clearly marked, and he noticed, and I had the opportunity of confirming his observation, that when a surface covered with fusain was exposed to dry air minute crystals formed upon it. The crystals were found to be sodium chloride and to contain a trace of magnesium chloride. When the fusain was exposed to moist air again, globules of liquid were formed. It is suggested that the source of the salt in the fusain may have been derived from the salt droppings, and may have gradually passed through the layer of porous fusain. The matter is of interest owing to the experiments which have been carried out by Mr. J. Ivon Graham, who shows the coal is practically impervious to gases.

It would appear from the above experiments that this observation could only be expected to hold provided that the masses are free from bands of fusain: if the layers of fusain will permit liquids to pass through them, it is obvious that gases would also find their way through these channels.

A separate experiment was carried out to determine the relative amount of sodium chloride removed from an aqueous solution. A piece of fusain and one of coal of exactly similar size were placed in separate beakers in a solution of sodium chloride in water. The two beakers were heated to about 80° Cent. for three hours. The pieces of fusain and coal were then removed, carefully washed with water in order to remove any salt from their surfaces, and then roughly dried with filter-paper. The amount of salt present in the coal and fusain was determined, as under:—

COAL USED—MOUNTAIN MINE.

	Grammes.
Weight of fusain taken	2·1672
After standing in salt solution, sodium chloride present in dried material	0·04869
Weight of coal taken	2·1869
After standing in salt solution, sodium chloride present in dried material	0·003397

The conclusion to be drawn from these experiments is that if coal comes into contact with water, the water will pass into layers of fusain. It would follow that much of the water present in coal may be contained in the bands of fusain. Attempts have been made to determine the relative percentages of water in fusain and coal from the same piece, but without success, owing to the fine state of division of the fusain and the rapid change in moisture-content which occurs on exposure to the air.

A considerable number of experiments have been carried out in which fusain from various coals was collected into heaps of a standard size, made by filling a small funnel and inverting it, when filled with fusain, on to a silica plate. The funnel was then removed and the cone of fusain ignited by means of a small gas-jet. Under the above conditions fusain continues to burn quite readily, but the combustion cannot be followed by the naked eye, as the mass only glows internally without the production of any visible fumes. There is evolved a faint odour resembling pine, which is similar to that obtained during the early stages of a gob-fire.

Further experiments were carried out in which the fusain was mixed with definite quantities of coal and then ignited in the standard manner. The coal and fusain in these experiments was accurately sieved so that it would pass through a 1/60-mesh and be caught up on a 1/90-mesh sieve. The samples of fusain and coal were obtained from the same seam. In the centre of the cone, which was $1\frac{1}{2}$ inches high, was placed a platinum-rhodium thermo-couple connected to a direct-reading galvanometer. Maximum temperatures were recorded. The following is the result of one of these experiments :—

Fusain. Per cent.	Coal. Per cent.	Maximum temperature. Degs. Cent.
100	0	525
90	10	560
80	20	585
70	30	605
60	40	605
50	50	600
40	60	590
30	70	510
20	80	Would not propagate a zone of combustion.
10	90	Do.
0	100	Do.

From the above it will be gathered that although the coal itself of the size quoted cannot be made to ignite and burn freely, yet when it is associated with a percentage of fusain of the same size the ignition proceeds throughout the mass. This result is given in order to emphasize the fact that fusain appears to possess special properties in relation to the rate at which it will burn. Experiments on these lines are being continued, and will be published in a later paper.

In view of the experiments described in this paper, emphasis may be placed upon the importance of the study of fusain as a possible factor contributing towards the spontaneous combustion of coal whether in mines, in the holds of ships, or in coal-stores.

The following summary of the main points advanced in the paper will doubtless be useful :—

(1) Fusain occurs in Lancashire coals in at least two forms, of which the more important is as a fine powder disseminated throughout the mass of coal. Aggregations of fusain contain a number of constituents which differ in composition from the coal-seam in which the fusain occurs.

(2) From the chemical analyses of a number of samples of fusain, it would appear that the percentage of oxygen and also the percentage of volatile matter present in fusain is considerably lower than that present in the coal in which it occurs.

(3) In the case of a certain number of seams, it is shown that if the surfaces parallel to the bedding-plane of pieces produced by natural fracture are examined, a considerable percentage of them are covered or partly covered with fusain.

(4) A method for the determination of fusain in coal has been elaborated, and although it yields only approximate results, the values are of interest as indicating that the amount of fusain in coal (Lancashire) may be 2·8 per cent.

The above method has also been applied to the determination of fusain in mine-dusts, and typical analyses indicate that the fusain in such dusts may be as high as 47 per cent. It has been found that the dusts from a dust-collector attached to a screen-room are in an extremely fine state of division, and that the finer material contains a higher percentage of fusain than the coarse. The amount of fusain present in the slurry from a washery has been estimated, and it is shown that about 25 per cent. of this material may be fusain.

(5) It has been found that the caking property of the slurry from a coal-washery is considerably lower than that of the coal itself. This applies especially where the percentage of fusain is highest. It is suggested, therefore, that care is required in distributing such material when it is being mixed with coal for coke manufacture.

(6) The approximate measurement of the degree to which a solution of salt will penetrate into a band of fusain has been made, and from this it is suggested that bands of fusain may be the means by which liquid is distributed through a seam of coal.

(7) Experiments are quoted showing that fusain burns with great readiness in the air, and produces a faint odour. No explanation of this phenomenon has been advanced, as it may be associated with either the degree of fineness or the chemical properties of the material. Work on this phase of the question is being continued.

I wish to express my thanks to Messrs. F. Bailey, A. Grounds, and A. McCulloch, and am especially indebted to Mr. N. Taylor for carrying out a considerable portion of the analytical work.

Mr. A. J. A. Orchard (St. Helens): Has Mr. Sinnatt examined the Little Delf of St. Helens, which contains a number of fusain partings? There is an area, near a large fault, where these partings disappear, and the coal, instead of having a dull appearance, is bright. The question I would ask is whether fusain, by pressure or temperature, can be changed into coal, or is it something quite distinct from coal?

Mr. T. H. Wordsworth (Buxton): I would suggest to Mr. Sinnatt that he should obtain a sample of coal from the Cannock Chase area. The whole of the coals in that district are non-coking, and it would be interesting to know the amount of fusain they contain. The author's description of the way in which fusain behaves when mixed with fine coal agrees with the manner in which the fine coal from the Cannock Chase district burns.

Mr. Sinnatt mentions that dust which has passed through a 1/200

mesh sieve contains a very high percentage of fusain, and that this dust might prove less dangerous than pure coal-dust. He seems to suggest that the dust used in the British coal-dust experiments was pure coal-dust. As the dust in those tests passed, I believe, in all cases through a 1/200-mesh sieve, it seems to me that the experiments made at Altofts were made with dust which contained a very high percentage of fusain. We cannot, therefore, look for any assurance of safety from the presence of fusain in the dust.

Mr. F. S. Sinnatt (Manchester): We have to recognize that there is a difference between coal ground so that it will all pass through a 1/200-mesh sieve and the dust found in the mine that will pass through a sieve of 1/200-mesh.

Mr. H. O. Dixon (Westhoughton): The subject is very interesting, but I do not quite know where it leads us. Are we to conclude that fusain in quantity is not dangerous, or is it ultra dangerous?

Mr. Sinnatt: My general impression at the moment is that it is not dangerous.

Mr. F. N. Siddall (Atherton): I intended myself to refer to the Cannock Chase and South Derbyshire coal, but Mr. Wordsworth has forestalled me. It is well known that gob-fires are very prevalent in that area. There is, in my opinion, a deal of fusain in that coal, and it is non-coking. The slack got in the Midlands is useful for commercial purposes only; it cannot be used for gas-making or for coking, and that is most likely because of the large proportion of fusain contained in it. Some time ago I discussed with Mr. Sinnatt the nature of fusain. We have heard to-day that it is the "suddy parting" or black stuff, but is it coal? One theory of the formation of coal is that originally a forest existed in a swamp, the roots of the trees being in water into which the *débris*—leaves, twigs, and so forth—and the trees themselves fell, and there underwent decomposition, caused by microbes or bacteria, as all decomposition is caused. It seems to me that fusain is practically the same as wood that has become rotten through dry rot. I understand that when examined under a microscope fusain is in the form of small rods, and I believe that dry-rotted wood is also composed of little rods, and that practically all the volatile constitutents have disappeared from it. I do not know whether I am correct, but I have the idea that fusain has been formed of wood that has rotted in the air, while the material which formed the coal has rotted in water. Bacteria which live and work in the air are called aerobic, whilst others which work in the absence of air are called anaerobic. The explanation may be that the bulk of the material fell into water and formed coal, and that a certain portion remained out of water in the air and was converted into fusain. This theory might account for more fusain being present in coal in some instances than in others. Mr. Lomax has described a portion of the Trencherbone Seam as spore-coal. Spores are not subject to dry rot, but are protected from it, so that one would not expect to find fusain in spore-coal, nor is it ever found there.

Mr. James Lomax (Bolton): As the question of the origin of fusain has been raised by Mr. Siddall, doubtless you would like some information of a microscopical character as to its nature.

Fusain is nearly always associated with sulphur in some form of pyrites. As an example, in many fusain bands there may be found the

remains of a flattened stem, one side of which may be composed of pyrites and the other of fusain. Between the two sides there may often be found a gradual transition from the one material to the other, or there may be a sharp division between the pyrites and the fusain.

I have recently received several specimens, the remains of stems or branches, a portion of each being fully pyritized and a portion being intermediate between pyrites and fusain. It has been mentioned that in some seams there is more fusain to be found than in others. That, in my opinion, is to be expected; for instance, it is seldom that one finds any large amount of fusain in a durain or spore-coal, this being owing probably to the nature of the vegetation from which the vegetable *débris* now forming the coal-substance was derived. On the other hand, in a soft bright coal fusain laminæ are more prevalent than in a durain or spore-coal. The soft coals are usually found at the base or at the upper portion of a seam, such as the Softs in the Trencherbone Seam or in the Barnsley Thick Bed. It is well known, microscopically, that the plants which supplied the *débris* for the coal-substance of the lower part were of a different nature from those which supplied the vegetable *débris* for the middle or hard coal.

If you search carefully in a fusain band you will sometimes see small twigs with a perfect structure of wood cells, on the outside of which is fusain. Such twigs have fallen from the parent plant and gone through some process that has converted the central part into vitrain, which is the bright looking coal. Whether this is due to bacterial action or not, I am not prepared to say, although there is evidences of bacterial action in some portions of a seam. I have not been able to satisfy myself that bacteria have altered wood and produced fusain.

In soft coal, where fusain is most common, hundreds of small pieces of fusain cross and re-cross one another, all showing apparently woody structure; but when examined carefully they do not exhibit the true structure of wood, but that of protoligneous* tissue of Williamson, tissues which we know to be the inner cortex or bark of the Lycopods, such as *Lepidodendron*, *Bothrodendron*, *Sigillaria*, and *Stigmaria*. In these there are three kinds of tissues: first, in the centre there is the medullary axis, consisting of primary and secondary zylem (true wood); outside there is a thick layer of inner cortex five to six times the thickness of the true wood; and, finally, there is the outer cortex and leaf-bases. Some portions of the latter are cork-like, whilst the inner cortex is unlike either cork or wood, being made up of short fusiform fibres or vessels without any reticulated, pitted, or barred cell-walls common to the true wood found in the medullary axis of the parent plant. I believe that in many instances where a thick deposit of fusain is found the major portion is divided from such tissues as I have just mentioned, namely, the inner and sometimes the outer cortex. In the one there would be plants which from their nature would be easily fusainized; for example, I have seen a considerable area of fusain the fibrous structure of which has been that of a small *Calamites*, small twigs, and cortical layers of other plants. Many such layers when seen in a vertical section under the microscope exhibit the exact cell-structure of the once living plant. Most of the fusain found in the ordinary laminated bands forming division-planes are fragmentary, one piece seldom covering more than a few square inches of area, although one may sometimes come across a layer that is exceptionally large.

* Primitive or first tissues resembling wood.

The probable reason why fusain bands are not prevalent in the Hards as well as in the Softs is that most of the plant-*débris* is in the form of spores and the remains of leaves, mainly the droppings from the huge Lycopodiaceous trees of that period, some of which, according to the size of the impressions found, would be more than 200 feet in height. Such trees would shed their foliage and fructiferous cones season after season, but not their bark. Occasionally one may find evidences of small branches and twigs which have a portion of the structural part, either the bark or the wood itself, converted into fusain, but little besides. When spore-coal changes abruptly into a soft coal, the division consists of an abnormal amount of fusain, and this, in my opinion, denotes a cessation in the growth of the Lycopodiaceous plants. By this means there would be a deposition of rotted or dead twigs and branches, and consequently a layer of fusain. We have again in the soft coal many bright and brilliant bands, which on examination are found to be what I formerly called " jetonized wood," but which later Dr. Marie Stopes named " vitrain." In a section from a fairly good specimen containing such bands one can see under the microscope that they are the remains of a stem, or a portion of a stem, the structure of which in many cases continues across the entire width of the band. More often than not they are decorticated—that is, they have lost their bark or cortex. In the same sample fusain layers are to be found, and when the fibres are carefully examined they are often found without the ordinary cell-structure of wood. By this, and especially if the fibres are fusainized, we may conclude that they are the tissues of the inner and outer cortex of some stem or other. I do not say that all fusain is the remains of the cortical layers of plants, but a large percentage is from that source.

With regard to the theory of the vegetation of Carboniferous times having lived and flourished in swamps, I do not think that such a view is correct, for the structure of the plant-remains found both in the coal and in the petrifactions shows that the habitat and soil must have been more or less dry—similar in many respects to the growth and deposition of a modern peat-deposit. Many species of trees during the period grew to a large size both in height and in girth, with large crowns of foliage totally unlike any plants found in recent swamp-deposits. Naturally the gradually thickening deposit would in time become more or less water-logged, as we now find to be the case in recent peat-deposits. These conditions apply to all fuel-deposits composed of terrestrial plants.

Dr. Wheeler and I expect in the near future to be able to examine a peat-deposit over 20 feet thick, in order to find out the difference and alteration between the lower and upper layers. In some of the layers whole stems more than a foot in diameter are to be seen, with their structure completely gone; others with the wood structure removed and filled in with a pulp-like substance; and others with a large percentage of cortical tissues only. By such an examination it is thought that some light will be obtained to show how the vegetable matter is altered and absorbed in different parts of the deposit from the base upwards.

The further discussion of the paper was adjourned.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,

Held in the Rooms of the Society, Queen's Chambers, 5, John Dalton Street, Manchester, November 8th, 1921.

Mr. SYDNEY A. SMITH, President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were elected :—

Associate Member—

Mr. John William Wilton, 289, Bryn Road, Bryn, Wigan.

Student—

Mr. James Stanley Swift, 53, Norwood Crescent, Southport.

DISCUSSION OF MR. F. S. SINNATT'S PAPER ENTITLED "A CONTRIBUTION TO THE STUDY OF FUSAIN."*

Mr. F. S. Sinnatt (Manchester): I am not prepared to deal to-day with the questions that were asked at the last meeting, because I am of opinion that they can only be satisfactorily answered by experimental evidence. I propose, therefore, to obtain samples and carry out work which will enable me to reply to the interesting questions that have been raised.

As an addition to my paper, and in continuation of the discussion, I have obtained from a dust-collector a sample of dust which has been separated by sieving into three fractions. The chief interest lies in the fact that 85·7 per cent. of this dust is so fine as to pass through a sieve of 200 meshes to the linear inch.

(Mr. Sinnatt placed a portion of this dust in a heap upon a porcelain tile and ignited the tip of the cone by means of a match. The fine dust readily ignited, and continued to burn for about an hour. The combustion was accompanied by a very faint odour, but with practically no evolution of smoke. When the heap of material was examined, a dull-red glow could be seen some distance into the cone. The substance left when the combustion was completed was black powder, which could not be distinguished from the fusain with difficulty. In many cases, however, the combustion proceeds until the material has been converted into ash.)

Mr. Sinnatt: I proposed to carry out these experiments at the last meeting with dust containing fusain which I had kept for about six months. On trying to ignite the material, however, many of the dusts failed to do so, although they had been found to burn readily six months previously. This observation may be of considerable importance, as it would appear that the dusts which had been kept for six months were not so active as the fresh dust. It follows that if dust

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 156.

containing fusain has been on the roads for some time, it may not be so active, and therefore not so dangerous from the point of view of ignition, as fresh fusain. Further experiments will be carried out in order to investigate this point; it is now placed on record as arising out of the experiment which has just been carried out. It may be added that if fusain is mixed with coal-dust, the combustion will proceed when the percentage of fusain is as low as 20 to 30.

Mr. T. H. Wordsworth (Buxton): Has Mr. Sinnatt seen the illustrations of the microscopical sections that were submitted to the Royal Commission of 1887 and published along with the report of the work done by Sir William Garforth at that time? As far as I remember these illustrations were drawn from the microscopical sections and then coloured. It would be interesting to know whether any of them were taken from fusain.

Mr. Sinnatt: I did examine certain of the illustrations in question. One that struck me particularly was described by Sir William Garforth as typical of dust that had been used in the explosion experiments. As far as I could judge, it contained a distinct amount of fusain.

Mr. James Lomax (Bolton): By arrangement with Capt. Sinnatt, I have prepared a number of illustrations to show the mode of occurrence and probable origin of fusain in coal-seams. These illustrations are taken from various seams containing fusain, and also from petrifactions containing fossil plants showing vegetative structure. The latter are introduced in order to convey some idea of the classes and forms of the plants from which the fusain bands and laminæ were derived.

It is a well-known fact that the substance of all coal-seams is composed of the remains of vegetation that grew and flourished during Carboniferous times. In the majority of seams—in fact, in almost all—the vegetable *débris* grew on the spot where it is now found as coal. Every seam when examined either megascopically or microscopically shows the order and sequence in which the various bands and laminæ were deposited. When thin slices or preparations are made, the microscope also reveals the nature of the constituents and bodies found in these bands and laminæ.

In many seams fusain is comparatively rare, and in others quite common; but in all seams it can be found in more or less small and large quantities, often in well-defined laminæ which form partings that cover a large area and divide the seams into zones. I have often pointed out that the vegetable *débris* forming a seam of coal was deposited in an ordinary sequence—that is, at the base of a seam the coal-substance is composed mainly of plant-remains of a comparatively low order and a dwarf-like habit. Such plant-remains form a bright, brittle, soft coal, but when alive and in their natural growth they would through periodical decay form a vegetable humus in which other plants of a higher order could flourish, and these in turn would deposit vegetable humus of their kind.

Similar conditions would continue throughout the whole of the time that plants grew on the spot where we now find a seam of coal. By such natural laws we have at the base, in almost every seam, a soft coal, the substance of which is derived from small and dwarf-like plants, and is succeeded by a bed of coal of a stronger nature, the *débris* of which was formed from a class of plants of a higher order and larger growth, these again being replaced by the giant Lycopods. The fossil remains of trunks and foliage branches found in the roof of the Arley Seam, near

Bolton, were more than 114 feet long; and large numbers of similar trunks have been seen in various parts of the British Coal-Measures.

It will be gathered, so long as the various constituents and bodies found in coal-seams are those derived from the droppings and remains of once living plants, that fusain or even iron disulphide must have been produced by chemical or other change in the various tissues of the original vegetable matter, leaving, as we now find, patches, lenticles, laminæ, and bands of pyrites and fusain.

Fusain is very often associated with iron pyrites in varying proportions; often when a thickish deposit, such as a pyritized stem, is found, the outer portion of the pyrites is covered with fusain. Pockets and lenticles of soft fuzzy coal (batt) are often found to be dull black in colour, batt being a mixture of black pyrites and fusain. Many of these pockets when examined microscopically are found to consist of a mixture of various plant-tissues, partly pyritized and partly fusainized. Fusain is often found in thin lenticles, as will be seen in some of the photographs of remains of small stems or fragments of large stems. The microscope shows the majority of these to be fragments of the inner and outer cortical tissues of the Lycopods or *Cordaites*. It is seldom that fusainized tissues of ferns or fern-like plants are to be found; sometimes fusainized fragments of the Equisetinæ or *Calamites* are met with.

These conditions can be accounted for by the fact that during Carboniferous times the two dominant classes of plants were the Lycopods and the Gymnosperms, the first including the *Lepidodendreæ*, *Sigillarieæ*, and *Bothrodendreæ*, and the latter the *Cordaites*, a few species of *Coniferales* or cone-bearing plants, allied to the recent Conifers, and some Pteridosperms or fern-like plants of a Cycadian character. All these attained a tree-like habit, growing a long straight stem or trunk, with a large crown of foliage and fructiferous branches, from which would be shed periodically leaves, small twigs, branches, fructiferous organs, and cortex or bark.

The rest of the Carboniferous classes of plants such as the Equisetinæ (*Calamites*) ferns and other moss-like plants would be dwarfed and have a ground habit of growth similar to plants of recent times in a forest area. It will be seen, therefore, that the great probability is that fusain is most likely to have been derived from the Lycopods and *Cordaites*.

In order to visualize or make clear the formation of fusain, I have had a few sections cut from stems found in the petrifactions or coal-balls in the Upper Foot Seam, Lower Coal-Measures (Figs. 1 to 18, Plate I.). Fig. 1 is cut transversely from a portion of an almost complete stem of one of the best-known fossil Lycopods, *Lepidodendron fuliginosus*. When the structural parts of the stem are examined we find it can be divided into four zones:—First we have the medullary axis or stele composed of the pith *A*, surrounded by a ring of primary wood *B*, on the outside of which there is a ring of secondary wood *C*, and associated and in contact with the outer edge of the secondary wood there are leaf-trace bundles and bast. The above constitutes the stele.

Surrounding the stele is the inner cortex *I C*, the outer cortex *O C*, the periderm *P*, and the leaf-bases *L B*. It will be noticed that a comparatively large portion of the stem is composed of cortex, and is divided into two zones. The inner cortex is composed of soft parenchyma, the cells of which would be easily destroyed, leaving, as seen in the section, a gap. The outer cortex is composed of similar shaped cells, the walls being very much thicker and stronger. The periderm and the outer cortical layers are much stronger still. The leaf-bases as seen

are attached to the latter, and form at the junction of the two a thick dense layer.

Before the alteration which would occur through the natural decay of the various tissues is described in detail the next figures should be examined.

Fig. 2 is a transverse section of a magnificent stem of *Ulodendron* (natural size). It will be observed that the structure is similar to that of *Lepidodendron fuliginosus*. There is the stele with a little secondary wood *A*, the inner cortex *I C*, the outer cortex *O C*, the periderm *P*, and leaf-trace bundles *L T*. It will be seen that the thick dense portion of the outer cortex and leaf-bases (as seen in Fig. 1) is missing. What probably happened was that owing to the age of the stem, or branch, the outer portion of the cortex and the leaf-bases were stripped or shed.

Another specimen showing the opposite is shown in Fig. 3, which is of natural size and cut from a specimen of *Lepidodendron harcourtii*, a species similar to *Lepidodendron fulginosus*. It will be observed that the whole of the tissues of the stele, the inner and the outer cortex, have been removed, and replaced by a fine mud-like substance, with here and there particles of vegetable matter. An enlarged portion of the same stem is shown in Fig. 4, a portion of the periderm *P*, and the extreme portion of the outer cortex with the leaf-bases *L B*.

Another specimen (Fig. 5) is also interesting, and is from a section cut from a specimen of *Lepidodendron selaginoides*, although the stele *S T* is composed of considerably more secondary wood. Stems of this species must have been very large both in girth and height. Impressions of the foliage of fructiferous branches are amongst the most common fossil impressions found in the roof-shales of many seams, and are known as *Lepidodendron lycopodioides*. It will be observed that the inner cortex is missing, leaving the stele, the outer cortex, with the periderm, and a portion of the leaf-bases.

It will be gathered from the above brief description of these four stems that the tissues of the Carboniferous Lycopods, although of a large size, were very soft and fragile, especially the tissues of the inner cortex. It will be noticed also that the stems contained very little true wood, only, as seen in Fig. 1, a comparatively thin ring of the stele. Figs. 1 and 2 (both photographs of the stems) show a complete sequence of tissues from the medulla to the periderm and outer cortex. They also show a large number of vascular bundles, or, in other words, leaf-trace bundles, each one of which extends from the secondary wood to the leaf-bases. The bundles are composed of a strand of four or five vascular or wood-like vessels. As these pass through the whole of the inner and outer cortex, besides being of a fibrous nature, they would bind or brace the softer tissues together, making the stem considerably stronger than it otherwise could have been, but for the nature of the leaf-trace bundles arrangement. Fig. 2 gives a good view of the leaf-trace bundles passing through the other tissues. If we look at Fig. 5 we shall see that a large portion of the inner and outer cortex had been destroyed and was replaced by a mud-like *débris* before petrifaction took place, leaving nothing but the periderm and leaf-bases. This, of course, was bound to occur if by some means the internal tissues of the inner and outer cortex were destroyed. It is not my intention to enquire into the cause of the destruction of these tissues further than to say that it might have been through bacterial or fungal action.

As has been shown, after the internal tissues were removed a hollow cylinder remained, composed of a portion of the periderm and the

extreme cortical tissues and leaf-bases. Similar hollow stems have recently been taken from the Horwich peat-deposit, consisting simply of the outer cortex or bark.

Such cylinders would naturally in course of time, except when filled with other material such as mud and fragmentary plant-remains, collapse and become flattened. Under such conditions they would form, according to the chemical and other alterations, thin or thick laminæ of fusain, pyrites, or coal.

A cortex of coal is often found in the fossil impressions of stems and other plant-remains in the roof-shales and mudstones. I have had hundreds of such specimens both as impressions and petrifactions. Returning again to Figs. 3 and 4, which illustrate alterations in the tissues, it will be noticed that the cylinder is bound by a black ring, which on further examination is found to be the thickened, fusainized, and partly pyritized tissues of the periderm *P*. Fig. 4 is a magnified portion of Fig. 3, and shows the tissues more clearly. The intensely black portion is fully pyritized, whilst the tissues immediately under the leaf-bases are partly fusainized and partly pyritized.

It will be gathered from the above that the cortical layers of stems could become fusainized, or might become pyritized, or, again, they may be a mixture of fusain, pyrites, and coal, and in many instances pure coal.

Another specimen, which will illustrate this phase quite clearly, is shown in Fig. 6, which is a photograph (one-third natural size) of a stem, probably some species of *Lepidodendron*, consisting of the rind or cortex *C*, which primarily and before being converted into a structureless and pure coal was similar to stems which, as already mentioned, became hollow cylinders. Inside the rind of coal can be seen the gap which formerly contained the modullary axis, the inner cortex, and outer cortex, and is now replaced by a mud-like substance. The specimen is unique in its way as affording clear proof of the fact that stems lost their internal structure, and that the rind or cortex afterwards became a pure coal-substance.

Most of the specimens hitherto dealt with are chiefly Lepidodendroid. By this it is not meant that there are not illustrations that could be used from the *Cordaites*, or even other Carboniferous plants. If we take all other fossil plants into consideration, the discussion could be extended, but, perhaps, without further gain.

My main object is to show the possible origin of fusain, and the manner in which it is found in a seam of coal. When derived from other plants besides those of the Carboniferous Lycopods, the methods would probably be the same. Another stem which might be briefly described, which throws a little light on the manner of decay and also the preservation of the wood-tissues, is from a *Cordaites* stem.

Fig. 7 is a transverse photograph of a stem of *Cordaites* (*Mesoxylon pœoxyloides*) from coal, having the tissues preserved in carbonate of iron and a little lime. The cortex is represented by a thin layer of coal not more than $\frac{1}{4}$ inch in thickness. It will be observed that such stems are very different from those of the Lycopods. The whole structural parts are fundamentally like those of a recent pine or conifer, the wood cells extending from the pith to the cortex, whereas in the *Lepidodendreæ* there is little wood and a large amount of soft friable parenchymateous tissue. Wood tissues of the *Cordaites* would not for several reasons decay as quickly as those of the Lycopods, although there may be found here and there stems that have lost a large portion of their

internal tissues. It more often occurs that stems from petrifactions are decorticated. In Fig. 7 there are places (at *Dc*) where rotting had commenced and been arrested before or during petrifaction. Often stems of *Cordaites* may be met with in the clarain and vitrain bands of coal. In the former they are mostly small and thin twigs; in the latter they may be of a comparatively large size. Sometimes the structure can be traced some distance across a stem which becomes structureless and thus pure vitrain; or sometimes a small piece of fusain may be met with, which is continuous with the vitrainized portion of a *Cordaites* stem, and which itself ultimately may become vitrain, showing that in some stems we get a portion that is fusainized, another a portion showing structure, and a portion that is vitrainized or structureless.

The following is a description of the fusainized plant-remains found in the coal-substance :—

It has been shown in the former description of the various stems how the cortical layers could produce fusain, and how it was possible that other parts of a stem could be fusainized. I admit that it is very difficult to account for all the fusain laminæ or bands found in a seam of coal, but fusain is undoubtedly the altered tissues of the Carboniferous plants already briefly mentioned. It is difficult to say with certainty how much fusain is derived from any given class of plants, for one must acknowledge that most of the tissues when fusainized lose their distinctive structure, although in some cases sufficient structure remains to indentify the species to which it belongs.

In the following figures, which are taken from vertical and horizontal fusain bands and from blocks of coal cut vertically, we have examples that give a good idea of the occurrence of fusain in various forms. Often one may find in a polished block or in a thin slice a number of thin lenticles of fusain, especially in some of the softer coals from the base of the seam. Such a slice is seen in Fig. 13, in which there are several white gaps, marked *Fu*, which are the gaps originally occupied by fusain; but, owing to the soft nature of the material, it was ground out in the making of the thin slice. In one portion near the middle of the slice, marked *Fu*, there is a fairly thick lamina, in which is embedded on the left a fragment of the inner cortex of a Lycopodiaceous stem. A similar fragment is also photographed with a magnification of about 15 diameters, showing the cellular structure (see Fig. 8); if this be compared with the vegetative tissue of the inner or outer cortex of a large stem of *Lepidodendron selaginoides*, it will be seen that they are both alike.

In Fig. 9, which is from a fusain parting from the Barnsley Bed, we have a picture of the outer cortex and leaf-bases of a *Sigillaria* or *Ulodendron* type of stem. In this case it is the outer cortex and leaf-bases which form the fusain laminæ.

We have again in Fig. 10 a photograph of a large and comparatively thick layer of fusain (about one-third natural size). By the form and appearance of the fusainized tissues it appears to be the outer cortex of a *Lepidodendron* or *Sigillaria*. In some places there are the ridges and position of the leaf-bases, although what is shown on the surface is the inner portion of the outer cortex. Another type of a fusain band is seen in Fig. 11, and it will be observed that it is composed of fusainized tissues of various kinds, such as the fragmentary portions of small stems, leaves, etc.

Similar laminæ to the above cover large areas and form for long distances well-defined partings in a seam. In thickness they are from $\frac{1}{8}$ to more than $\frac{1}{2}$ inch thick.

It has already been mentioned that one portion of a stem may be fusainized and the adjoining portion may be pyritized. If Fig. 12 be examined it will be seen that a long section of a stem with the tissues on the side (*Fu*) are fusainized, and the other tissues on the side (*Py*) pyritized. I often found specimens of this kind, and they are more or less common in many seams.

Fig. 13 has already been examined, but it should be taken in comparison with Figs. 14 and 15, which are introduced to show the difference in the fusain laminæ in three classes of coal. Fig. 13 is a soft coal, the ingredients of which are composed of fine humic matter, in some places almost structureless, breaking up into disc-like pieces, with a large number of irregular fusain partings and pockets, usually found near the floor and sometimes near the roof. Fig. 14 is a much harder coal, composed of a strong laminated coal-substance, with here and there thin detached fusain laminæ (*Fu*). The laminated coal-bands are chiefly composed of leaf-laminæ, mainly the foliage leaves of *Cordaites*. There are one or two vitrain bands and also a few laminæ composed of resinous and other bodies. The fusain laminæ are mainly the remains of some fragmentary portions of stems, or of small fusainized twigs.

Fig. 15 is taken from a polished block of hard spore-coal (" durain " of Dr. Stopes). It has a finely-laminated appearance, the composition being mainly of spore exines, megaspores, and microspores, with here and there alternating leaf-like laminæ. In such coals fusain is seldom found in thick laminæ, but here and there small lenticles may occur, and they are often the cortical layers from some of the *Lepidodendreæ* or *Sigillaria*.

It may be taken for granted that less fusain is met with in the durain coal than in the soft or semi-soft coals, although I have found in a seam where the spore-coal has suddenly ended a thick band or bed containing a large quantity of fusainized wood and cortical tissues, above which may, and often does, occur a dirt-band. Sometimes the dirt-band may be thin; in other cases it may be thick. After the dirt, another bed of coal may appear, this being similar to the bottom bed, of a soft nature, and containing fusain laminæ. I will leave it to the members to account for the sudden cessation of the durain, the appearance of the inferior coal and fusain, and afterwards to the reappearance of a dirt-band and then a soft coal.

The last three figures are samples of dust taken from a haulage-road in the Arley Seam, Abram, the roadway being 6 feet high and 12 feet wide.

Fig. 16 was taken from the floor; Fig. 17, 3 feet from the floor; and Fig. 18, from the roof. These figures need little explanation, and have been made to show the comparative amount of coal-dust and fusain between the floor and roof. The fusain can be recognized by its feathery and flake-like appearance (some of the flakes are marked *Fu*), coal-dust being more or less angular or cubical. It will be readily observed that the bulk of the fusain is from the region of the floor, and the smallest amount from near the roof. These three figures tell their own tale.

In conclusion I may say that much more might be said on the subject from the palæobotanical point of view, but it will be gathered from Capt. Sinnatt's paper that fusain is of more importance from a mining point of view than has been hitherto thought to be the case.

The President (Mr. Sydney A. Smith): Although the word " fusain " is new to many of the members, the substance referred to has been known

to us as " mother-of-coal." I was called in to advise upon the extinction of a fire in the lower part of the seam at the Broad Oak colliery about the year 1889. A quantity of soft coal, fusain, and inferior coal had caught fire, and it was difficult to put it out. The fire continued to smoulder, just as in the experiment we have witnessed this afternoon. A considerable quantity of pyrites was mixed with the coal, and we came to the conclusion that the steam from the engine on going up the back brow had caused heating of the pyrites and set fire to the soft coal or mother-of-coal. We endeavoured to put out the fire with water, but that simply set the pyrites working again, but after fighting the fire for a week we got it under. There was no doubt that it was the burning of the fusain which caused the extension of the fire.

The interesting photographs shown on the screen have added considerably to our knowledge on the subject, but I cannot quite understand why fusain is nearly always found in small stratums (as it were) between the coal, and Mr. Lomax's explanation has not yet made the reason clear. I have here the *Colliery Guardian* of January 28th, 1898, which contains on page 157 an abstract of a paper by Prof. A. de Lapparent on the origin of coal, and from this it appears that it was M. Grand'Eury who in the year 1876 originated the name " fusain," which he says is " the dull coal which soils the fingers, representing portions of stalks the anatomical structure of which has disappeared." Further on Prof. Lapparent, in discussing the drift-deposit theory of the formation of coal-seams, gives M. de Sapporta's explanation why fusain is found in bands, as under :—

" Seldom did fallen stems remain entire. But they swelled and opened, while the soft and porous parts were the first to be disaggregated, the dense and fibrous portions becoming detached from the cortical mass which, more tenacious, often smooth and firm outside, resisted longer than all the rest. Of the fern trunks there only remained the outer case or the inside fibres disintegrated; and of the Cordaites, Sigillaria, and Lepidodendra nothing but the cortical region. The detached leaves formed other accumulations; and all of them obstructed certain places at the bottom of declivities and at the outlet of valleys, waiting for the passage of water for giving up matters that had arrived at very different degrees of decomposition."

Mr. Sinnatt : Dr. Marie Stopes accepted fusain as the name used by M. Grand'Eury for this particular substance, and that gave rise to vitrain, clarain, and durain as names for the three other constituents of coal.

Mr. Lomax : I have read some of M. Grand'Eury's theories and conclusions, with all of which I do not agree. M. Grand'Eury had not in his day access to coal-sections like those that can be made to-day.

With regard to the preservation or otherwise of plants in water, experiments have been made with plants sealed in jars of water, and although some have been kept for four or five years, they showed very little change, especially if the solution contained either a little salt or lime. As opposed to the drift theory of Grand'Eury, my view is that all coal-seams, or at least more than 90 per cent. of them, have been formed from vegetation grown on the spot and not from drift material.

DISCUSSION OF MR. A. L. LOVATT'S PAPER ON "METHODS OF DEALING WITH COAL-DUST."*

Mr. F. N. Siddall (Atherton): This is one of the most interesting papers that have been read recently from the point of view of discussion. Every mining engineer or colliery official has doubtless his own views on the subject and on the Regulations of the Coal Mines Act dealing with the matter. In order therefore to open a discussion upon this important subject, I propose to follow Mr. Lovatt's method and describe, briefly, the means adopted at the Atherton Collieries to carry out the Regulations.

(1) The screen-rooms are completely isolated from the downcast shafts. The tipplers are closed, and centrifugal fans collect the dust made on the shaker-screens, which dust is conducted into large tanks, and these are quenched with water from the coal-washer.

(2) Dust-tight tubs of riveted iron have been used since the commencement of the Eight Hours Act in 1908. The average life of these tubs is from 8 to 10 years, and 10 to 12 per cent. depreciation covers all maintenance.

(3) The roadways are constantly being cleaned up, and the coal-dust is sent out of the pit.

(4) Very shortly after the Hulton explosion of December, 1910, stone-dusting was adopted at these collieries in mitigation of the dangers of coal-dust. One of the under-managers, Mr. Thomas Yates, invented a means of spreading stone-dust by compressed air. His apparatus consisted of a 2-inch T-pipe fitted with an ejector nozzle—very similar to that described by Mr. Lovatt—and connected by a flexible hose to the compressed-air main. This apparatus was tried on January 20th, 1911, and worked well. Similar spreaders have been in use at all the firm's collieries ever since.

Experiments were carried out by Mr. Yates at the Victoria Colliery to ascertain the quantities of coal-dust deposited and the quantity of stone-dust as deposited from a blowing station. Six tin plates, each 2 feet square, were placed two at a time on the floor of three manholes situated 360 yards apart in the main engine-brow. The amount of coal-dust deposited in ten workings days was collected and weighed and found to be $2\frac{1}{4}$ ounces, equal to a deposit of 351 pounds over a length of 1,000 yards on the floor alone, or 35 pounds per day. The roadway was 10 feet wide and 7 feet high, and 1,200 6-cwt. tubs were drawn up the brow each day.

The same tin plates were employed to find out what quantity of stone-dust was deposited in the same roadway from a blowing station situated 900 yards from the brow. Two plates placed 100 yards from the blowing station on the floor in the centre of the brow yielded $1\frac{3}{4}$ ounces of dust; two plates at 200 yards, $\frac{1}{2}$ ounce; and at 300 yards, $\frac{1}{2}$ ounce; and apparently the same thickness of deposit up to 500 yards. The stone-dust could be easily seen in the return airway, it having travelled round the face and covered every object on the way. The distance from the blowing station to the return was 1,600 yards.

The air-current had a velocity of 350 feet per minute in the engine-brow, which has an area of 70 square feet. The compressed air had a pressure of 30 pounds per square inch, and 1,000 pounds of stone-dust were used. This experiment was made on January 28th, 1911.

From the above results it will be seen that Mr. Lovatt's statement

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 311.

(page 316), that "the lighter particles of the stone-dust are held suspended in the airway for distances of over 1,000 yards" is correct; but exception may be taken to his following corollary that "although there may be a dust-cloud passing, it does not follow that it is doing effective work." What is effective work? According to the conclusions arrived at by the Coal Mines Explosions Experimental Committee and embodied in the Regulations, it would appear that if the coal-dust deposited is intermixed or overlain by 50 per cent. of inert matter, the place may be considered to be satisfactory.

The rates of deposition of coal-dust having been found from such experiments as those of Mr. Yates, it is obvious that his further experiments to ascertain the quantity of stone-dust deposited in the same roadway show plainly that it is by no means necessary to have compressed-air blowing stations so near as Mr. Lovatt would make out, provided that the ventilating current is moving fast enough to carry the requisite amount of stone-dust with it. For instance, in Mr. Yates's experiment the coal-dust was deposited at a rate roughly of 0·03 ounce per square foot per day; whilst the stone-dust at distances of 200 to 500 yards from the blowing station was deposited at about 0·06 ounce per square foot per day, or double the quantity necessary to provide a 50-per-cent. mixture.

The present stone-dust grinding-mill was erected on May 1st, 1912; previous to that date shale was ground in the mortar-mill and sieved by hand. The mill is an edge-roller grinding-mill used in brickmaking, having two heavy edge rollers and a revolving pan. In the floor of the pan there are eight segment plates; four are blank and four are perforated with 400 $\frac{3}{32}$-inch holes per square foot. The ground material falls through the perforations, and is delivered by a bucket-elevator to a revolving riddle, 5 feet long, 3 feet in diameter, of hexagon shape, and of fine mesh. All material that does not pass through the riddle is returned to the grinding-pan. The fine dust is dropped through funnels into 2-cwt. bags. One man attends to the mill, keeps the riddle in order, breaks up the shale into 3 by 3-inch pieces, and bags the ground stone-dust. He can on an average grind to the requisite degree of fineness twenty 2-cwt. bags in a shift of 8 hours. As two shifts per day are worked, some 24 tons of dust are produced per week.

The shale used is from the roof of the Bickershaw Seven Feet Seam. A portion of the shale of average appearance was obtained from a lump, pulverized, and then analysed, with the following result:—

	Per cent.
Moisture	1·16
Ash	91·21
Combustible matter and combined water	7·63

The ash from the above was analysed as follows:—

	Per cent.
Silica	65·42
Ferric oxide	4·24
Alumina	25·34
Lime	0·30
Magnesia	0·75
Sulphur trioxide	0·81
Alkalis	3·14

The material is slightly high in silica, but this constituent is present largely in a collodial form, as was shown by an examination of the free and combined silica. It was found that the total amount of quartz and felspar in the shale was 36 per cent.

The microscopical examination of a section of the material proves that the silica is dispersed throughout the alumina, and that the quartz crystals are extremely small and hardly recognizable as such.

It is an easy matter to spread stone-dust with compressed air, but in the absence of compressed-air mains the problem becomes much more difficult and expensive. One is then usually driven to spreading the dust by hand. At the Atherton Collieries small bags containing not more than 40 pounds of stone-dust have been found to be the best means of conveying the dust into the drawing-roads, etc., but even so they wear out rapidly, owing to their being dragged along the floor. We found that a cut-down canvas kit-bag lasted the longest of any bag tried. We endeavoured to obtain some disused Government horse nose-bags, but were unsuccessful. The work of spreading the stone-dust by hand is done during the night or afternoon shift, or when no men are working on the return side of the place that is being dusted, and spare lads or datallers perform the work. One may say roughly that one man per 100 tons of output is engaged on this work.

We have fitted up on a tub-bottom a small hand fan, which was originally made for ventilating the tunnels in the trenches, and is Government surplus. With this instrument, and having one of our usual compressed-air spreaders attached to the original ventilating hose, two men can stone-dust four or five times the length of roadway that can be done by hand, whilst the dust is distributed better and in a more even covering over the whole area of roadway.

The sampling is done by the officials of the mine. A small scoop, shaped like a domestic dustpan, but with the top cover nearer to the lower edge than in that instrument, and provided with two handles, has been found most useful for collecting the sample. A band is swept round the periphery of a roadway, including roof, floor, and sides, in the one sweep, with a painter's flat varnish brush some 4 inches wide. Such a sample or brushing is taken every 10 yards over the 50-yard length prescribed in the Regulations. The requisite number of brushings are collected in the dustpan and thoroughly mixed. A quantity is then sieved in a tin provided with a 28-mesh gauze, and the resulting fine sample is put into a 2-ounce flat tin, similar to a vaseline or tobacco tin of that capacity.

It is a great waste of time and energy to cart a large sample of rough dust about the pit. Ten or twelve fine samples contained in 2-ounce tins can be collected in a shift, carried about the pit quite comfortably, and all the unwanted waste left behind as each sample is taken.

The analyses of the samples so taken have been performed, up to the present, by the Lancashire and Cheshire Coal Research Association, Manchester. A scheme has been prepared and a laboratory erected at the colliery in order that the routine work of making such analyses may be performed on the spot and the chemists of the Research Association freed for more important work. This laboratory would have been at work long since but for the delay of the strike and more important constructional work at the collieries. The analyses of some 200 or 300 samples show that the average contains some 2 per cent. of moisture, 60 to 70 per cent. of ash, and 40 to 30 per cent. of combustible material in places where stone-dusting has been carried out.

It is interesting to note that the eye alone is no criterion as to the condition of a roadway. On several occasions when a place was considered to be right, it was found that this was not the case; and, again, where the conditions appeared to be bad, the analysis of a sample showed a surprising amount of incombustible material to be present.

The quality of shales varies very greatly for stone-dusting purposes. Often an analysis of an apparently very suitable shale will prove it to be most unsuitable, owing to the presence of free silica. In this connexion a microscopical examination is far better than a chemical one, as it shows up the size and number of quartz crystals—the dangerous element—better than a chemical analysis. On the other hand, a shale, or other material suitable for stone-dusting, may, upon analysis, show a large percentage of combustible matter—which may be actually carbonaceous material, or most often is really combined water, or the " water of crystallization," or carbon dioxide driven off from carbonates or similar compounds.

Mr. John Gregory and Mr. E. O. Simcock in the discussion of Mr. Lovatt's paper drew attention to this point, and it is worthy of note by the authorities. It is hardly fair to users of stone-dust that only the inert matter can be counted in favour of the user, and that other constituents, possibly of great value, should actually count against him. To take an extreme case: certain shales and clays found in coal-mines contain a considerable proportion of aluminium sulphate, the formula for which is $Al_2(SO_4)_3.16H_2O$, showing what a large volume of water of crystallization is contained therein. The bulk of this water is driven off by incineration, but would appear in a sample of roadway dust as " combustible matter," when in fact it is very much the exact opposite. I say " very much " because, whatever may be said or, in fact, be the truth of the action of carbon dioxide evolved from stone-dust in an explosion, there can be no doubt that the driving off of water of crystallization must have an enormous heat-reducing result.

In the first place a great amount of heat is required to drive it out of any compound; secondly, the water so driven out has a great capacity for heat, so tending to cool down surrounding objects; and, thirdly, steam will allow no combustion of carbon to take place in its presence. Incidentally it may be mentioned that these alum-bearing shales and underclays are more frequent than many colliery people are aware of, and might prove a source of revenue at present neglected.

Ordinary roof-shale of a suitable analysis is probably the most valuable material that can be found for the purpose of stone-dusting, from the point of view expressed by Dr. Haldane in reply to the original discussion, in that it is more " effective and free from objection as regards risk of lung trouble or inconvenience to persons at work " than almost any other material. The best shale for the purpose partakes of the nature of a soapstone or mudstone. It is soapy to the feel, soft in the mouth, and melts away in water. A very fair idea of the value of a shale for stone-dusting purposes can be obtained in a rough way by biting a small sample and grinding it up with the teeth. If the shale is readily reduced to a fine powder, leaving no grit to the tongue, it can be said to be fairly free from injurious silica. In fact, a particle of the correct shale, of whatever size, always tends to disintegrate on exposure to the atmosphere, or rather to the water in the air. If placed in water it will, in time, become well nigh impalpable, and so in the lungs it can do no harm. The question of fineness with such a shale is not, therefore, so important as with a harder material that will not fall or disintegrate on exposure. With regard, however, to the matter of fineness of the stone-dust, the remarks of Mr. Simcock in the original discussion are worthy of note, but his criticism with regard to the quantity of 200-mesh dust near a blowing station is of no great weight, as when compressed-air blowers are used the dust must be put on when working backwards against the air-current. Therefore each blowing

station or portion of roadway will receive a layer of finer and finer dust as the actual operations recede.

Was not, however, the matter of fineness really decided by the authorities, having in view the proposition that stone-dust should be continually delivered into the air whilst coal was being worked in order to "constantly dilute and render harmless the noxious" coal-dust as it was made? This proposition overlooked the fact that such an emission of stone-dust would be noxious in itself to the workers having to live in such an atmosphere.

Mr. Harold Stephenson (Tyldesley): One point which struck me was in regard to the use of the injector for distributing the dust so as to get it travelling along with the air-current. We had a similar apparatus to that originally used by the Atherton Collieries, and it occurred to me that possibly by simply agitating the dust with compressed air, without using the spraying apparatus, we would get the same effect. We did this, and discovered that the dust carried just as far by using the rubber pipe as with the apparatus.

Mr. Siddall: The first time we tried stone-dusting Mr. Yates turned his hose into a tub of stone-dust, and it was spread all over the place. The only purpose in using the sprayer was that the men should not be blinded. I should like to have Mr. Sinnatt's views in regard to the combustible and non-combustible matter contained in the samples of stone-dust. Some who took part in the original discussion made a very strong point about that. They used limestone, but if limestone be used when it is burned, half the weight of the stuff is driven off, and that all counts as combustible material. For that reason it was given up.

Mr. H. O. Dixon (Westhoughton): Is it not a fact that credit is given for the water in the stone-dust used?

Mr. Siddall: Water of combination is not in moisture, but in "combustible matter." It cannot be extracted as moisture; moisture is that which is driven off at 212° Fahr., any loss of weight above that temperature being reckoned as "combustible matter." The new Regulation just issued, but dated November 2nd, 1921, clears up the whole matter and makes due and proper allowance for all water of crystallization, etc., in stone-dusts. I had no knowledge of this Regulation when drawing up my notes for discussion on Mr. Lovatt's paper.

Mr. Sinnatt: As a rule, in most of the shales examined, the value seems to be about 7 to 8 per cent. of water of combination, and that water of combination is not driven off during the ordinary determination of moisture.

Mr. Siddall: We had several shales analysed to see which was the best, and one was condemned because it had too much free silica in it; another was condemned because, oddly enough, it contained a great deal of carbonaceous matter.

Mr. Sinnatt: That is so; I forget the exact figures, but the point was it contained a considerable amount of carbonaceous matter—to such an extent that I believe it worked out at something like 20 per cent. in the original shale; 20 per cent. of organic matter or combustible matter would be introduced with the material. In reality, the stone-dust was only effective to the extent of 60 per cent., and therefore it was not economical.

Mr. James Lomax (Bolton): We have a great many shales from various collieries, many being suitable and others not. A shale, described as soapstone, upon being pulverized showed the resulting grains and particles to be more or less irregular and to have feathery edges, whereas an ordinary mudstone, which does not feel soapy, breaks up into fine particles of all shapes. I might mention that fuller's earth was used extensively in experiments made at Eskmeals. If a sample of fuller's earth were made into a microscopial section and examined, large numbers of quartz crystals would be found. These when crushed fine would make particles almost like glass-dust. It is such material as this that is dangerous to health. It was against the use of such dust that Dr. Haldane raised a warning, whereas in the case of the soapstone-dust there is practically no danger. If a collier is working in a dusty place, and if dust of a soapy nature gets into his throat, he can quickly cough it out, whereas if the dust contains particles of glass-like quartz he cannot do so, as the fine fragmentary particles of quartz stick to the tissues of the throat and lungs.

Mr. Vincent Bramall (West Didsbury): Many collieries are going to a great expense in putting down crushing plant, some firms spending from £1,000 to £1,500. There are so many different kinds of stone-grinders that no one appears to know which is the best. If the right shale is obtained—soft blue shale—and it is passed through a stone-breaker and then through one pair of burr stones, probably the right size would be got at a trifling expense.

Mr. A. L. Lovatt (Kidsgrove) wrote: In the discussion on my paper Mr. Siddall takes exception to the statement respecting the inability of a stone-dust cloud 1,000 yards away to do effective work. The experiments carried out by Mr. Yates at the Victoria Colliery are very interesting, but they show only the rate of deposition of coal-dust and the amount of stone-dust required to comply with the regulations at that colliery. As, however, the rate of deposition of coal-dust must vary at each colliery, so must the amount of stone-dust required and the distance at which effective blowing can be done.

I pointed out in my paper that the distance between the blowing stations can be ascertained only by experiment. Later on I pinned my faith to the travelling blower because it gives a more uniform deposit of stone-dust all along the roadway.

I congratulate Mr. Siddall on the excellent way in which he has opened the discussion and added useful information to a most important subject.

THE NORTH STAFFORDSHIRE INSTITUTE OF MINING ENGINEERS.

FORTY-NINTH ANNUAL GENERAL MEETING,

HELD AT THE CENTRAL SCHOOL OF SCIENCE AND TECHNOLOGY, STOKE-ON-TRENT, NOVEMBER 22ND, 1921.

Mr. J. R. L. ALLOTT, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been previously nominated, were elected :—

ASSOCIATE MEMBER—

Mr. GEORGE H. RITCHIE, Basford, Stoke-on-Trent.

TRANSFER FROM ASSOCIATE MEMBER TO MEMBER—

Mr. JAMES B. SPROSTON, M.C., Newcastle, Staffs.

TRANSFER FROM ASSOCIATE TO MEMBER—

Mr. V. H. M. BARRETT, Dundee, Natal.

ABSTRACT OF ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

The membership as at July 31st, 1921, was 193, being an increase of 17 over the number for the previous year.

The accounts show a credit balance of £194 14s. 6d., as compared with £229 3s. 5d. for last year. Of this amount £150 is invested in 5-per-cent. War Bonds, the remainder (£44 14s. 6d.) being in the current account. The loss on the year's working is, therefore, £34 8s. 11d. This loss was foreseen by the Council, as indicated in the last Report, and the steps which were then under consideration, and which have since been taken, to increase the subscriptions will, it is hoped, cover any likely increases in working costs during the next few years.

The arrears of subscriptions paid during the year 1920-1921 amount to £33 14s., as compared with £54 4s. received during last year. The Council has written off arrears amounting to £25 4s., and the arrears now outstanding amount to £114 6s., as compared with £79 12s. for the previous year.

At the Annual General Meeting on November 22nd, 1920, it was decided to alter the Rules relating to qualifications for membership and bring them again into line with the Bye-laws of The Institution of Mining Engineers. At the same meeting it was decided to adopt the recommendation of the Council to increase, for the time being, the rates of subscription as follows :—Members, £3 3s. ; Associate Members, £3 3s. ; Associates, £2 2s. ; Students, £1 10s. ; Subscribing Members, £3 3s.

The Council invited Dr. J. S. Haldane, F.R.S., to become an Honorary Member of the Institute, and is gratified to record his acceptance.

The North Staffordshire Institute of Mining Engineers: Abstract of Revenue Account for the Year ended July 31st, 1921.

Income.	£ s. d.
To Balance brought forward	229 3 5
,, Current subscriptions	280 7 0
,, Arrears for years 1917-1918, 1918-1919, and 1919-1920 ...	33 14 0
,, Subscriptions paid in advance	3 6 0
,, Interest on £150 5-per-cent. National War Bonds	7 10 0
	£554 0 5

Expenditure.	£ s. d.	£ s. d.
By The Institution of Mining Engineers:—		
Calls for year 1919-1920	3 0 0	
,, ,, 1920-1921	188 15 0	
Back *Transactions* for members in arrears	17 17 0	
		209 12 0
,, Printing and stationery		46 7 7
,, Salaries, auditing, reporting, travelling and meeting expenses		61 2 6
,, Postages, telephone, and telegrams		16 10 0
,, Incidental expenditure		2 3 6
,, Library		23 10 4
,, Balance made up as under:—		
5-per-cent. National War Loan	150 0 0	
At bank	44 14 6	
		194 14 6
		£554 0 5

Abstract of Building Fund Account.

Receipts.	£ s. d.
To Balance brought forward	731 16 7
,, Dividend on 5-per-cent. National War Bonds	30 0 0
,, Bank interest	5 2 9
	£766 19 4

Payments.	£ s. d.
By Balance	766 19 4
(Investment in 5-per-cent. National War Bonds, 1927, £600)	
	£766 19 4

There have been five General Meetings during the year, and five papers have been read and discussed.

The Council has requested the President to postpone the decision as to the award of the Medal which he kindly offered at the last Annual Meeting, so as to enable papers read in the coming year to compete, it being felt that the stoppage in the coal industry this year precluded many members from reading papers.

Owing to this stoppage, the usual summer excursion meeting was not held.

The Council deeply regrets to have to record the death of two members, namely, Mr. E. Adams and Mr. Hugh L. Wilkinson.

The Honorary Librarian reports that during the year ten volumes of exchanges have been bound, and a further twenty volumes are at the binders. The work of bringing the Library catalogue up to date is in hand.

On the motion of the President, seconded by Mr. H. Mason, the Annual Report and Accounts were unanimously adopted.

Mr. J. R. L. Allott was unanimously re-elected President for the ensuing year, and delivered the following Address :—

PRESIDENTIAL ADDRESS.

By JAMES R. L. ALLOTT.

I have again to thank the members for the confidence shown in re-electing me President for another year. I little thought when I had the privilege of addressing you a year ago that the honour would fall to me a second time. I am afraid that I shall but indifferently deserve it, but I hope that I shall neither seek to escape the responsibilities nor shirk the obligations; and throughout the year it will be my ambition to merit the trust and goodwill that you have indicated to-day in again electing me to this important office.

It is fitting that my first act should be to place on record the help which I have received throughout the year from the Past-Presidents, Members of Council, and our Secretary. It is extremely comforting to feel that one has so capable and willing a body of helpers, and I tender them my sincere thanks.

For the mining and allied industries the past year has undoubtedly been one of unprecedented difficulty. The Great War has brought in its train industrial disaster, and we are faced with the problem of restoring industry to its pre-war stability. The war has perhaps naturally produced grave disturbances—conflicts between employers and employed, and between both and the Government—so that we are experiencing now such a trade depression as has never been known for centuries. Unfortunately, this collapse is not confined to the coal industry; every department of trade and commerce is affected—iron and steel, engineering, cotton, shipping, etc., are all suffering in like manner. The depression is world-wide; America with 5,000,000 unemployed is even in a worse state than we are, whilst conditions in other countries can only be described as appalling.

Looking back to the conditions existing in coal-mining before the war, the difference to-day is very striking. Then there was interest and individual effort in work; now it is lacking. Then the cost of things produced was an economic figure; it is not so to-day. Then our coal and manufactures were produced and carried to the buyer at a reasonable freight; to-day the cost of this alone closes many markets. It was possible then to carry on an industry with reasonable remuneration for all; it is not the case now. In pre-war days collieries were able to extend, thus finding employment for additional workers, with beneficial results for all. There was then sufficient cheap fuel to enable other industries to manufacture and develop; coal and other goods were available for export at prices which commanded a ready market, and cheap foodstuffs were imported in return.

A great deal more might be said about the present situation, but the outstanding fact is that if the industries of the country are to emerge from this depressed condition they must produce more per individual, and reduce the cost of production. Above all, we must have cheaper coal. This is the problem for mining engineers to-day, and to this our skill and energy must be directed.

The question which we are asking ourselves at the moment is: can we improve our output and results? In seven hours we have to raise as much coal as was formerly raised in eight hours. We must prepare it for the market and offer it at a price which other industries can afford to pay. This can only be done by a very determined effort. There must be co-operation between all sections of the staff and the workmen, but even then it is very doubtful whether a true economic balance can be realized with miners working at the coal-face about six hours a day.

For the first time in mining history there has been laid down principles of co-operation between employers and employed. The workers are now enabled to participate in the profits of the industry. They benefit in proportion to their efforts towards increased efficiency and economy, and we are entitled to expect much from this co-operation. There is also a Welfare Fund of something like a million pounds sterling a year to be devoted to their social wellbeing.

On the question of reducing the costs in connexion with the production of coal, a rigorous campaign against waste of all kinds must be carried out. Waste of fuel, timber, and stores must be prevented. Most of us know how the consumption of these materials grows on a large works unless rigidly checked. Mechanical devices for reducing working costs must be applied wherever possible, together with the most economical methods of raising steam and using it efficiently. These are problems essentially for the engineer, but in which the workmen can also give much help.

The call for economy demands more attention to the importance of the standardization of mechanical details. Much has already been done by The British Engineering Standards Association, but much remains to be done. It appears to me that those details which in colliery practice are used in large numbers, and most of which are subject to heavy wear and tear, should have attention. It is over fifty years since Sir Joseph Whitworth provided us with the standard screw-thread, and we are all well aware of the benefits obtained from its general adoption. It is a great pity that Continental and American practice differs. Standard pipe-flanges have been designed, and main-line rails and fish-plates are standardized, all of which can be more easily and cheaply made by mass production. The variation in the sections of pit-rails is

infinite; each maker has his own particular section, although the weight may be the same. This variation leads to confusion and expense, often compelling the user to await the convenience of the manufacturer, if he must use throughout his mines the same section of rail.

Details of electrical, mechanical, and general appliances could all be standardized, both in materials and manufacture, and the result would be to cheapen the cost of production.

Quite a lot has been said of late regarding the important question of transport, and no one considering the economic aspect of trade generally can overlook the fact that the freight charges in this country are a national handicap. There is not a single colliery or business that is not vitally affected by the cost of railway transport, and we are living in hopes that reorganization will bring us some relief in that direction. We cannot overlook the fact that Continental railways have done much that we would do well to emulate.

During and since the war a great deal of the time and energies of our members has been absorbed in irksome and often unnecessary duties, such as the preparation of statistics and reports, and the continual alterations in the systems of computing wages, thus taking them from the scientific and technical sides of management.

It is a relief to know that we will now be able to devote our time to our special duties, and once more turn our minds to matters benefiting our industry and profession. We can now look for help from our members to increase the usefulness of our Mining Institutions, and we shall no doubt see the results in our future *Transactions*.

The immense number of problems awaiting investigation are of great interest, especially to the younger members, and our responsibility to future generations makes it imperative to remember that the success of the Institute depends upon the personal exertions of every one, and that its vitality can only be maintained by individual effort.

Mr. S. Barber proposed and Mr. A. Marshall seconded a hearty vote of thanks to the President for his services during the past year and for his Presidential Address, and the resolution was accorded with acclamation.

The President : I appreciate very much this vote of thanks. It is our duty to do everything we can in connexion with Institutions like ours. It is advantageous to meet together and compare notes and experiences; and during the coming year we might usefully have informal discussions, even if we cannot always have formal papers, at the periods appointed for the meetings. It has been unfortunate that during the past year so many of our meetings have been interfered with through various causes. I hope the young members will come forward and compete in real earnest for the Medal offered for the best paper.

THE INSTITUTION OF MINING ENGINEERS
AND
THE INSTITUTION OF MINING AND METALLURGY.

UNVEILING OF WAR MEMORIALS,
By Field-Marshal The Right Honourable EARL HAIG,
K.T., G.C.B., O.M., G.C.V.O., K.C.I.E.,
On Thursday, November 24th, 1921, at 3 o'clock p.m.

ORDER OF CEREMONY.

Opening Remarks on behalf of the Institutions by Mr. F. W. Harbord, C.B.E., President of The Institution of Mining and Metallurgy, and by Colonel W. C. Blackett, C.B.E., Past-President of The Institution of Mining Engineers (in the absence of the President, Sir John Cadman, K.C.M.G.).

The Field-Marshal's Address.

Unveiling of the Memorials.

The Unveiling of the Memorials was followed by a Solemn Silence of one minute, after which the Field-Marshal pronounced the words

"Their Name Liveth for Evermore,"

and the "Last Post" and the "Reveille" were sounded by Trumpeters of the Honourable Artillery Company.

Mr. F. W. Harbord (President of The Institution of Mining and Metallurgy): My Lord, Lady Haig, Ladies and Gentlemen: We are assembled to-day, not to mourn the loss of our relatives and fellow engineers who fell on active service and whose names are inscribed on our Roll of Honour, but to perpetuate their memory and to draw fresh inspiration from the remembrance of their glorious deeds and example.

We wish at the same time to remember those who have passed away since the Armistice as a direct result of their service in the field, and we wish also to remember those of our brother engineers who are still with us, but who, as the result of grevious wounds or ruined health, will continue to suffer all their lives.

We are proud to have with us to-day Field-Marshal Lord Haig, not only because of the great position he occupied as Commander-in-Chief but also because of his self-sacrificing devotion to the interests of ex-service officers and men, and we are deeply grateful for the presence of the gracious Lady who so nobly seconds her distinguished husband's efforts.

Lord Haig, on behalf of The Institution of Mining and Metallurgy I thank you for so kindly acceding to our request to unveil this Memorial presented in grateful remembrance by the Members, Associates, and Students of the Institution.

Colonel W. C. Blackett (Past-President of The Institution of Mining Engineers): My Lord Haig, Lady Haig, Ladies and Gentlemen: When we look back upon all that has gone on during

the War, we mercifully find it impossible, even in our imaginations, to endure again the miseries that we then experienced. But we have the wondering remembrance left to us of the deeds and sacrifices of our wounded and our dead. Some of us have the names which are on the marble tablets before us deeply bitten into our memories because they were our sons, our fathers, our brothers, the elect and best of our race, chosen for the greatest sacrifice that man can make for man.

They have served, these men, in all branches of His Majesty's Forces at one time and another, in the air, on the sea, on land, and many of them were concentrated in Tunnelling Companies under the ground. They served variously, all valiantly, and pray God we may never think that they have served in vain.

Graves are for the dead, but there are graves in France and Belgium into which living men walked and never again came forth alive. Their courage was not mere hazard without fear, but sprang from their being resolutely minded for a just cause. It is our hope that some day this sacrifice will fructify into a great harvest which will choke out the weeds of malice and envy and hatred and selfishness and jealousy which are so rife in the world to-day. When Death opened the gates of Fame for these men, he closed the doors of envy and jealousy. Would that he could have shut these doors also for the living!

We do most earnestly hope that in no far distant future we shall achieve, slowly it may be, a greater peace than has been known to us yet. At the present moment our Peoples throughout our great Empire are more distracted than they have been possibly before, and a bitter cry is going up saying, "Is Peace then only with the Dead?" Let us hope that before very long our Empire will achieve Peace among the living.

My lord, on behalf of The Institution of Mining Engineers, which I have the honour of representing, the members of which are wide-spread throughout the world, I beg to add to Mr. Harbord's thanks to you the gratitude of every member of our Institution for the kindness which you and your good Lady are exhibiting to us to-day.

Earl Haig: Mr. Harbord, Colonel Blackett, Members of The Institution of Mining and Metallurgy and of The Institution of Mining Engineers, Ladies and Gentlemen: Two good reasons urged me to accept your invitation to come here to-day to unveil these Memorials to your gallant dead. The first and the more general one is that on all such occasions I am able to pay a personal tribute to a section of those many thousands of brave men who fought under my command in France, and under my command paid the last and greatest sacrifice that love of King and Country can demand of true and loyal citizens. The least that I can do—I who, acting myself in the execution of my duty, asked and obtained so much from them in the execution of theirs—the least that I can do, I say, is to join with those who knew and loved them in honouring their names.

My second and more particular reason for wishing to come here is that you have afforded me an opportunity to say a few words of especial thanks to a body of men whose work in France seldom drew upon itself much notice or glory at the time, but was surpassed by none in the demands it made upon the skill, the courage, and the resolution of the individuals concerned, or in the services it rendered to the Army as a whole.

One thinks naturally of the Battle of Messines and of the mighty series of explosions that tore great gaps in the German line on June 7th, 1917, and gave the signal for one of the most successful of our attacks. That was the work of the special Services to which you sent so many

gallant men, and it was indeed a signal triumph of British mining in war. Yet few, I think, outside those who took part in the work and benefited by its results realize the immense amount of steady, persistent toil in every circumstance of peril, surrounded by danger in a form that might well appal the stoutest-hearted, that went to the preparation of that triumph. Few, I know, realize how vast, how important to the safety, comfort, and success of our troops was the other work of our miners, work that was little commented upon in the Press, but yet went on steadily and continuously day after day and year after year all along the whole British Front. There was no truce at any time to the warfare that went on underground. There was no respite from the toil which the needs of the Army imposed upon those who were masters of the art of digging underground; only there were periods of redoubled activity of more than common strain. Every offensive undertaken by us right up to the days of the last great series of advances meant a fresh call upon the energy, the industry, and the courage of those special Services upon whom the due preparation of these offensives so largely depended.

Tunnelled approaches had to be constructed from great distances, dug-outs built for headquarters, dressing stations, and shelters generally. Every big offensive made demands of that kind. An immense amount of work was done for the Somme. The preparations for the Battle of Arras attracted little attention compared with those for the Messines Battle, but they were no less valuable.

Then later, when the day of the elaborately mounted attack was over, the Tunnelling Companies found a new work, hardly less arduous or dangerous, in the discovery and the removal of many thousands of German mines.

I am talking to those who themselves know something of these things, but it is right that others should know too, and here, where you are met to pay the last honour to comrades, members of your Institutions, who actually accomplished these things and did nobly in the doing of them, I am glad to thank, not for myself only, but on behalf of the whole Army, this gallant body of men.

This is an occasion for deep sympathy with those who have lost so much and see in these Memorials the commemoration of their private sorrow. It is an occasion, too, for admiration and gratitude towards men who gave so much, all that men could give, for the liberty and honour of their fellow countrymen. It is more even than that; it is an occasion for us who remain to take courage from the example of those who have so bravely gone before us. The cause for which these honoured dead gave the last full measure of their devotion is still ours to uphold. The task to which they gave their lives is laid upon us and on our children to complete.

Therefore, as days go by, we should look upon these Memorials with quiet sorrow but with lasting pride. They should be to us lessons not only of what men have done but of what true men can do. Then shall we, and generations to come, draw hope and inspiration from the memory of what these men accomplished in the strength of their faith and their patriotism, so that in the days of difficulty now and hereafter the great Commonwealth of Nations to which we all belong, which we all love, shall never lack for men who will, as did those whose names are here written, count their own lives as nothing in their country's service.

To the Glory of God and the Memory of these Gallant Heroes, I unveil these Memorials!

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM OCTOBER 30TH TO DECEMBER 3RD, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
	Oct.		14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
Sun. ..	30	0	16′5	16′5	16′0	15′5	15′0	18′5	19′5	18′5	17′5	16′5	15′0	16′0	16′5
Mon. ..	31	1	16·5	16·5	15·5	15·5	14·5	18·5	21·0	21·0	18·5	13·0	11·5	11·5	16·0
	Nov.														
Tues. ..	1	1	14·5	14·0	14·0	14·5	14·5	18·0	21·0	21·5	20·0	17·0	16·0	15·5	16·5
Wed. ..	2	0	15·5	16·0	16·0	14·5	14·0	18·0	19·5	18·0	16·5	15·5	15·5	15·5	16·0
Thur. ..	3	0	15·5	16·0	16·0	15·0	14·5	16·5	19·0	18·0	16·5	16·0	14·5	14·5	16·0
Fri. ..	4	0	15·5	16·0	15·5	14·5	13·0	16·0	19·0	17·5	16·0	15·5	15·5	15·5	16·0
Sat. ..	5	2	15·5	16·0	15·5	15·0	13·5	16·5	20·0	20·0	19·5	16·0	11·5	1·5	15·0
Sun. ..	6	2	5·0*	14·0*	17·5*	19·0	16·5	17·5	20·5	18·5	18·0	15·5	12·0	11·5	15·5
Mon. ..	7	1	13·0	13·0	15·0	16·0	14·5	15·5	18·0	17·5	15·5	15·0	13·5	13·5	15·0
Tues. ..	8	1	16·0	15·0	15·0	14·5	14·0	17·5	19·0	17·5	16·0	15·0	14·5	9·0	15·0
Wed. ..	9	1	12·0	15·5	14·5	14·5	14·0	17·5	20·0	18·5	15·0	14·0	13·5	10·5	15·0
Thur. ..	10	1	14·5	15·0	13·5	15·0	15·5	17·5	21·0	20·5	17·5	14·5	12·0	13·0	16·0
Fri. ..	11	0	15·0	16·0	15·5	14·0	13·0	16·0	18·5	17·0	15·5	15·0	15·0	14·0	15·5
Sat. ..	12	0	15·0	15·5	15·0	14·0	13·5	16·5	18·0	16·5	16·0	15·0	15·0	15·0	15·5
Sun. ..	13	1	15·0	15·5	15·5	14·5	14·0	16·5	18·0	17·5	16·5	15·0	11·5	13·0	15·0
Mon. ..	14	1	8·0	11·0	13·5	13·5	13·5	16·0	17·0	16·0	15·0	13·0	14·0	13·5	13·5
Tues. ..	15	0	14·5	15·0	15·0	14·0	13·0	16·0	17·0	16·0	15·5	15·0	12·0	12·5	14·5
Wed. ..	16	2	15·0	15·5	16·0	15·5	16·5	17·5	20·0	16·5	15·5	10·5*	4·0*	7·0*	14·0
Thur. ..	17	2	12·5*	11·5*	15·5*	19·5*	14·5	17·5	19·5	18·5	14·0	12·5	3·5*	9·0*	14·0
Fri. ..	18	1	14·5	15·0	18·5	17·0	15·0	17·5	19·5	16·5	14·5	8·0	10·5	14·0	15·0
Sat. ..	19	1	14·5	15·5	14·5	15·0	15·0	16·0	16·5	14·0	13·5	14·5	14·0	14·0	15·0
Sun. ..	20	0	14·0	15·0	15·5	14·5	14·5	15·5	16·5	16·0	15·0	14·5	14·0	14·0	15·0
Mon. ..	21	1	13·5	13·5	15·0	15·0	14·0	16·0	18·0	16·5	14·0	11·5	13·0	12·5	14·5
Tues. ..	22	1	13·5	15·0	14·5	13·5	13·0	15·0	16·5	16·5	14·0	13·5	14·0	13·5	14·5
Wed. ..	23	1	14·0	14·5	15·0	14·5	13·5	16·0	17·5	17·5	17·0	9·0	7·5	11·5	14·0
Thur. ..	24	1	12·0	14·5	15·0	14·5	13·5	16·0	17·5	15·5	14·5	14·5	14·0	14·0	14·5
Fri. ..	25	1	13·5	14·5	14·0	14·0	14·0	16·0	17·5	16·5	15·0	13·0	13·5	14·0	14·5
Sat. ..	26	0	15·0	15·0	15·0	14·0	14·0	15·0	16·0	15·0	14·5	14·0	14·0	14·5	14·5
Sun. ..	27	0	14·5	14·0	13·5	14·5	15·5	16·5	17·5	17·0	16·0	15·0	13·5	14·0	15·0
Mon. ..	28	1	14·5	11·5	12·0	13·0	14·5	15·5	16·5	15·5	14·5	14·0	14·0	14·5	14·0
Tues. ..	29	0	15·0	15·5	15·0	14·5	14·0	15·5	16·0	15·5	15·0	14·5	14·0	14·0	15·0
Wed. ..	30	0	14·5	15·5	15·0	14·0	13·5	15·5	17·5	16·0	14·5	14·5	13·5	12·5	14·5
	Dec.														
Thur. ..	1	0	12·0	14·5	15·0	14·0	13·5	16·0	18·5	18·0	15·5	13·5	13·0	13·0	15·0
Fri. ..	2	0	14·0	15·0	15·5	15·5	15·0	16·5	17·5	16·5	15·5	14·0	12·0	12·0	15·0
Sat. ..	3	1	15·0	14·5	14·5	15·5	14·5	15·0	16·5	15·5	14·5	14·5	13·5	13·5	14·5

Diurnal Inequality (i.e., departure from mean value for day).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
November, 1920	−2′0	−0′6	−0′9	−0′7	−0′8	−0′7	−0′6	−0′7	−0′3	+1′2	+2′4	+3′3
October, 1921	−1·3	−0·9	−0·6	−0·8	−1·0	−1·0	−1·4	−2·4	−2·4	−0·7	+2·1	+4·3
October, 1920	−1·6	−1·2	−1·4	−0·9	−1·0	−1·0	−1·5	−2·2	−2·0	−0·2	+2·6	+4·9

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
November, 1920	+3′7	+2′9	+2′4	+1′8	+1′0	+0′1	−1′1	−1′8	−2′1	−2′5	−2′1	−2′0
October, 1921	+5·0	+4·4	+3·1	+1·9	+0·9	+0·3	−0·7	−1·5	−2·1	−2·3	−1·8	−1·1
October, 1920	+5·7	+5·3	+3·8	+2·0	+0·9	+0·4	−0·6	−1·4	−2·3	−3·1	−3·0	−2·1

* Large disturbances during this interval.

Mean Value for Month.

November, 1920. 14° 27′·2.

October, 1921. 14° 16′·4.

October, 1920. 14° 28′·1.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

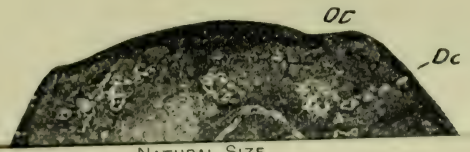
" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The above values were obtained from measurements made after "smoothing" the curves.

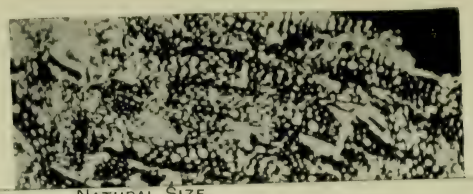
To illustrate Mr. James Lomax's Remarks on Mr. F. S. Sinnatt's Paper entitled

FIG. 4.—LEPIDODENDRON HARCOURTII.
MAGNIFIED 15 DIAMETERS.



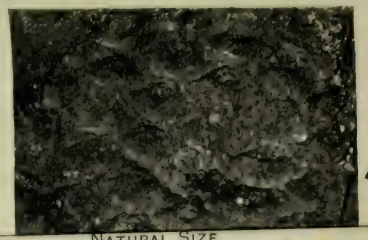
NATURAL SIZE.

NATURAL SIZE.



NATURAL SIZE.

REMOVED; CORTEX CONVERTED INTO COAL. ONE-THIRD NATURAL SIZE.



NATURAL SIZE.

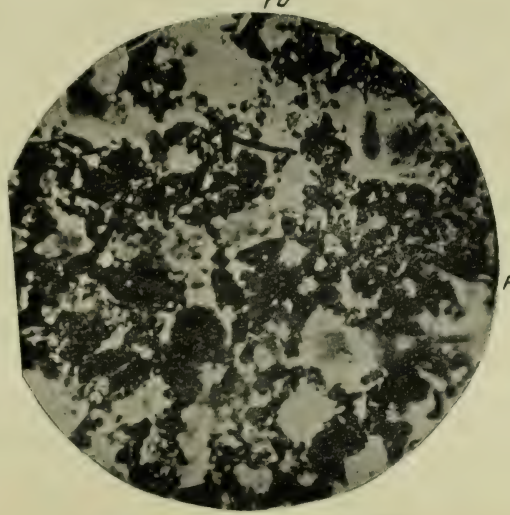


FIG. 16.—COAL-DUST FROM FLOOR.
MAGNIFIED 15 DIAMETERS.

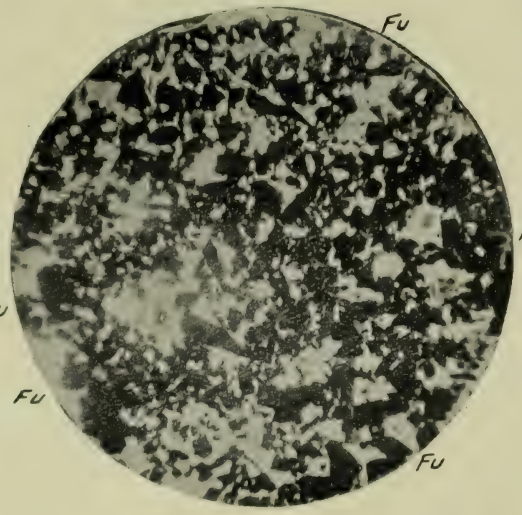


FIG. 17.—COAL-DUST 3 FEET FROM FLOOR.
MAGNIFIED 15 DIAMETERS.

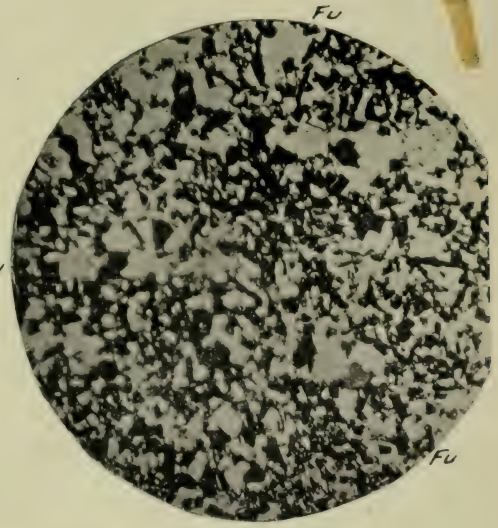


FIG. 18.—COAL-DUST FROM ROOF.
MAGNIFIED 15 DIAMETERS.

To illustrate Mr. James Lomax's Remarks on Mr. F. S. Sinnatt's Paper entitled

"A Contribution to the Study of Fusain."

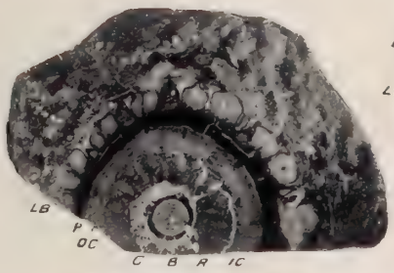


FIG. 1.—LEPIDODENDRON FULIGINOSUS.
NATURAL SIZE

FIG. 2.—ULODENDRON MAJUS (?).
NATURAL SIZE.

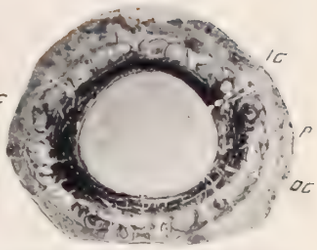


FIG. 3.—LEPIDODENDRON HARCOURTII.
NATURAL SIZE

FIG. 4.—LEPIDODENDRON HARCOURTII.
MAGNIFIED 15 DIAMETERS.

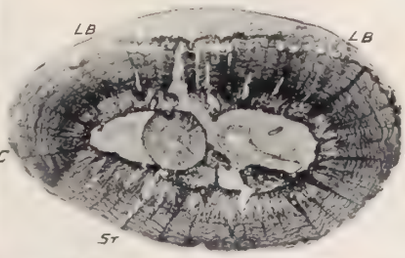


FIG. 5.—LEPIDODENDRON SELAGINOIDES.
NATURAL SIZE

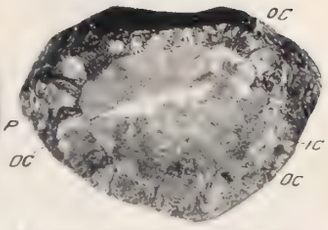


FIG. 6.—STEM WITH THE CENTRAL TISSUES REMOVED. CORTEX CONVERTED INTO COAL. ONE THIRD NATURAL SIZE.

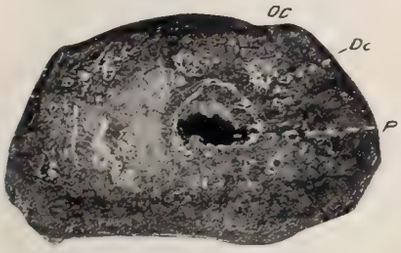


FIG. 7.—PETRIFIED CONIFEROUS STEM FROM COAL.
HALF NATURAL SIZE

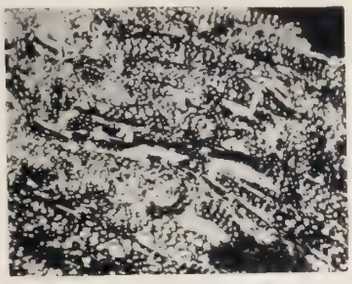


FIG. 8.—FUSAIN SHOWING STRUCTURE.
MAGNIFIED 15 DIAMETERS.

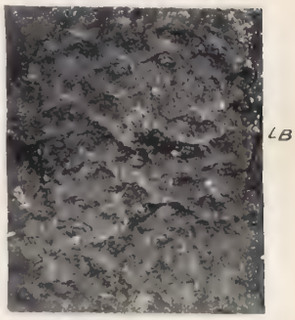


FIG. 9.—ULODENDRON CORTEX.
REDUCED SIZE

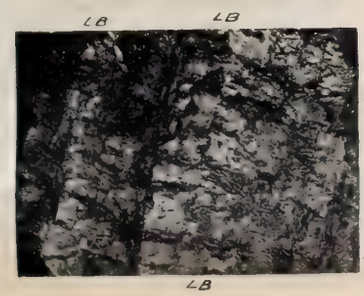


FIG. 10.—FUSAIN. HALF NATURAL SIZE.

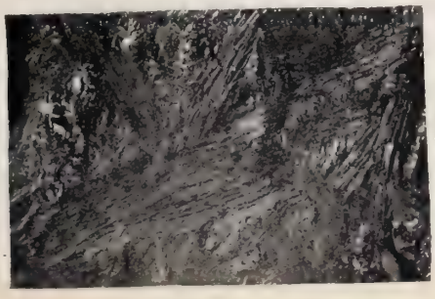


FIG. 11.—FUSAIN. NATURAL SIZE.

FIG. 12.—FUSAIN AND IRON PYRITES.
NATURAL SIZE

FIG. 13.—SECTION OF COAL (SOFT).
NATURAL SIZE.

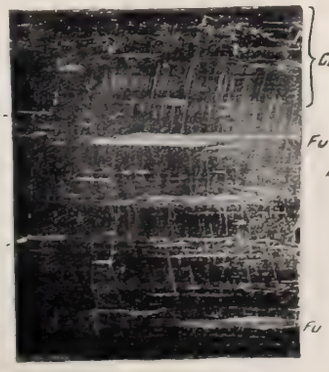


FIG. 14.—SECTION OF COAL (CLARAIN).
NATURAL SIZE

FIG. 15.—SECTION OF COAL (DURAIN).
NATURAL SIZE

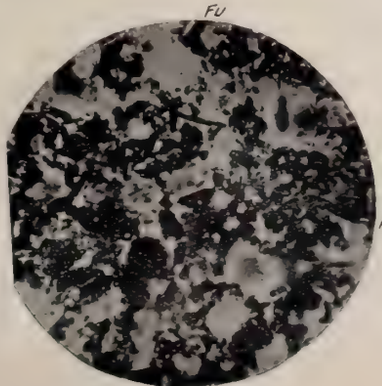


FIG. 16.—COAL-DUST FROM FLOOR.
MAGNIFIED 15 DIAMETERS.

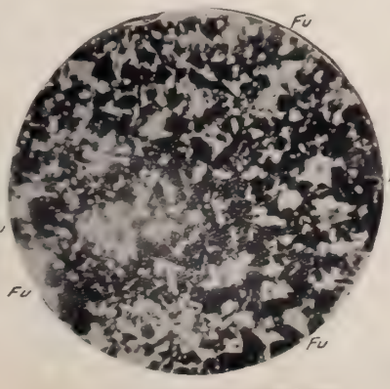


FIG. 17.—COAL-DUST 3 FEET FROM FLOOR.
MAGNIFIED 15 DIAMETERS.

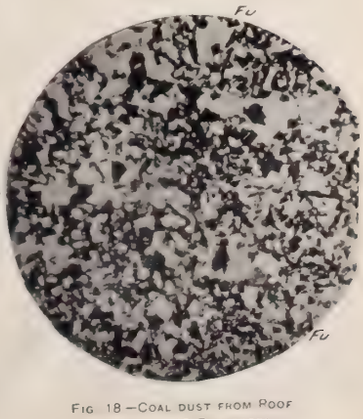


FIG. 18.—COAL DUST FROM ROOF.
MAGNIFIED 15 DIAMETERS.

THE SOUTH STAFFORDSHIRE AND WARWICKSHIRE INSTITUTE OF MINING ENGINEERS.

GENERAL MEETING,

HELD AT THE UNIVERSITY, EDMUND STREET, BIRMINGHAM, DECEMBER 5TH, 1921.

Mr. J. R. FELTON, PRESIDENT, IN THE CHAIR.

DEATH OF MR. T. J. DAVIES.

The President proposed a vote of condolence with the relatives of the late Mr. T. J. Davies, a Past-President of the Institute.

The resolution was carried in silence, the members standing.

ELECTION OF MEMBERS.

The following gentleman, having been approved by the Council, was elected :—

ASSOCIATE MEMBER—

Mr. ARTHUR STANLEY LOWE, Oaken, Wolverhampton.

DISCUSSION OF MR. W. WICKHAM KING'S PAPER ON "THE PLEXOGRAPHY OF SOUTH STAFFORDSHIRE IN AVONIAN TIME."*

Prof. W. S. BOULTON (Birmingham University): The Institute is greatly indebted to Mr. Wickham King for submitting a paper so crowded with accurate and acute geological observation and so rich in promise for the future development of the South Staffordshire Coalfield, but more especially the concealed and deeply-buried coals in the surrounding district. The model of the Thick Coal which he exhibited to the members for the first time is the happy issue of the fruitful co-operation between the pure geologist and the practical mining engineer, and will be a lasting monument of Mr. King's patience, skill, and untiring industry. Whatever reading of the model we adopt, and by whatever theories we seek to explain the complicated folding and faulting which it exhibits, the main facts are fixed and certain, and will serve as a basis for mining calculations in the future, while provoking discussion as to the nature and sequence of the disturbances which the coalfield area has suffered throughout the greater part of geological time.

The late Dr. E. A. Newell Arber in 1916 read a paper on "The Structure of the South Staffordshire Coalfield, with Special Reference to the Concealed Areas and to the Neighbouring Fields,"† in which he opposed the view held by Prof. Charles Lapworth and others that the

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 151.

† *Ibid.*, 1916-1917, vol. lii., page 35.

structure of the visible coalfield as a whole is anticlinal, for Dr. Arber says "the visible coalfield is unmistakably a syncline and not an anticline." He further maintained that the minor anticlinal folds within the coalfield are entirely of post-Carboniferous age. It was in my mind at the time to combat Dr. Arber's views, but, owing to his serious illness and death soon afterwards, the adjourned discussion of that paper has never taken place. Mr. King's model now shows clearly that the coalfield, taken as a unit, is essentially a faulted anticline, and that the areas covered by Red Rocks to the east and west of it are synclines or basins. But superposed on this anticline we have a complex of faulted dome and basin dominated by two sets of earth-movement—N.W.-S.E. (Charnian) and N.E.-S.W. (Caledonian). It would have been clearer to the general reader, perhaps, if Mr. King had emphasized the fact early in his paper that these terms are used purely in the directional sense and without prejudice as to their geological age.

I agree that the pre-Coal-Measure folding is largely Charnian in direction, but I think that Mr. King scarcely lays sufficient emphasis upon the Caledonian folding of the Coal-Measure floor. In his map of the floor on page 159, the general strike of the pre-Coal-Measure Formations is north-east, and the dominant movements at the close of the Silurian-Downtonian in this area seem to have been Caledonian, as in Britain generally. But in the South Staffordshire area these movements were profoundly modified by an already existing Charnian structure. I discussed this subject at some length in my Presidential Address to Section C of the British Association at Newcastle-upon-Tyne, in 1916, and laid stress upon the importance of a study of these two sets of movements in pre-Coal-Measure time when considering the question of winning coals deeply buried under newer formations. I do not know whether Mr. King will agree, but I regard the north and south strike of the Silurian rocks in Dudley Castle Hill, the Wren's Nest, etc., as the resultant of the superposition of the Caledonian folding on the older Charnian.

But for this Institute a more important consideration is the probable original discontinuity of the coals laid down in great separate hollows or basins in the corrugated floor. Within the confines of the visible coalfield shown by the model the Thick Coal, for example, is, or was, continuous, because the relatively small hollows that existed were soon filled up and smoothed over by Coal-Measures below the Thick Coal. But where the amplitude of pre-Coal-Measure folding was greater, or where denudation had not progressed so far in pre-Coal-Measure time, the Thick Coal and other workable seams may have been deposited in discontinuous basins in the South Midland area. In my opinion not the least merit of the present paper is that it proves and estimates the extent of the folding and faulting before the Coal-Measures were deposited, which in some places, as at the south-eastern end of the Russell Hall Fault, is much greater in extent than in post-Coal-Measure time.

The movements posterior to the Coal-Measures seem to have been mostly along the old lines, and more especially Caledonian lines, and to consist of narrow sharply-compressed anticlines and troughs or actual faults. I should like to ask Mr. King whether he has any evidence that the north and south (Pennine) faults in the area, such as the Great Eastern Boundary Fault near Aldridge and the boundary fault to the west of the Swinford Basin, were in part of pre-Coal-Measure age, or whether they were probably due entirely to post-Coal-Measure move-

ments, and owed their direction to the conflict of the north-eastern and north-western systems of folds.

The latter part of the paper, which deals with the distribution, lithology, and derivation of the breccias and conglomerates in the Red Beds overlying the productive Coal-Measures, might appear at first sight of almost purely academic interest. It is a field of research which in the Midlands Mr. King has made peculiarly his own. That such a study is capable of yielding results of high practical value by indicating areas barren of coal I am convinced. But we must exercise caution, and not push that line of reasoning too far or pretend to an accuracy which does not exist. When the promising areas are marked out in the light of such geological evidence as is contained in the paper, it will still need the enterprise of the financier and mining engineer to prospect by trial boring, though we may hope with less chance of failure than if such work as Mr. King's had never been done.

The President (Mr. J. R. Felton): I think we shall all agree with Prof. Boulton that the paper is a valuable contribution to our knowledge of the geology of the district. Its chief value lies in the fact that it is a permanent record of the work done by Mr. Wickham King for many years, and the paper will be referred to again and again in years to come because of its valuable information. It is of the greatest interest to have laid before us in so lucid a way information as to the earth-movements and denudations affecting the floor upon which the Coal-Measures have been deposited. The paper has also a great practical value by indicating to mining engineers the areas which should in any exploration of the future be avoided, as well as those which might be explored with hope of success.

Dr. Leonard J. Wills (Birmingham University) wrote: The interest of Mr. Wickham King's paper is more than local because of the supposed community of origin of the South Midland Coalfields. Principles established in South Staffordshire should be of value in understanding other coalfields. The author appears to have assumed that there was a pause in the earth-movements after "Avonian" times, and before the deposition of the Coal-Measures. It would be interesting to know whether he has considered the possibility of movement actually during the deposition of the measures below the Thick Coal. A consideration of the thicknesses and constitution of these measures in relation to the folds and faults might well be found to indicate depression in the synclinal basins contemporaneous with the infilling of the basins by sedimentation. If this were proved, and possibly Mr. King may have in his possession the data to prove or disprove it, the principle involved might be applied to the interpretation of other coalfields and the hidden coalfields of the Midlands. Geologists and mining engineers are very grateful to Mr. King for his work on South Staffordshire plexography, and I should like to remind him of someone's definition of gratitude as "a lively sense of favours to come."

Mr. F. Raw (Birmingham University): Mr. King's geological work is well known, and especially relates to the Coal-Measures and the rocks immediately below and above them. The first geological work of Mr. King in my recollection was that on the conglomerates and breccias in the Permian rocks above the Coal-Measures. That was pioneer work, both methods and conclusions being absolutely new. Latterly Mr. King has greatly extended our knowledge of the Old Red Sandstone rocks below. But all the time—I believe for about 30 years—he has been collecting

data relative to the composition and structure of the South Staffordshire Coalfield. Mr. King's knowledge of the subject is unique, and his conclusions are more fully set out in his present paper than in any previous communication. His acquaintance with these matters is so very much greater than that of anyone else that it is really very difficult to make any substantial contribution to the discussion. Mr. King in 1916 described his map and model of the Thick Coal—a magnificent piece of work—and it is more than time that it was published in a form in which all could use it. Cannot this Institute undertake to publish it? I should suggest a map on the layer system, with a different colour for each 500 feet, and contours drawn across at each 100 feet, and on a scale, say, of 2 inches to 1 mile. This would be a valuable addition to the *Transactions*.

Now Mr. King has burrowed down below the level of the Thick Coal; he has presented to us the floor of the coalfield in both its composition and its structure, and has discussed its deformation both before and after Coal-Measure time. The paper contains many perhaps to some unfamiliar stratigraphical terms, and it would have been easier to follow if Mr. King had given us definitions of those terms. Take the term "Downtonian." In the sense in which it is used in the paper, might it not be regarded as Mr. King's own offspring?

The paper is specially important in that it represents an enormous volume of original work. There are some things in it which I am delighted to see, as they confirm some of one's own pre-conceived notions whilst banishing others. From the exposures of the base of the Coal-Measures one concluded that the original floor of the Coal-Measures was very regular as compared with its present form, and that it consisted in the extreme east of Cambrian quartzite, and higher beds in order dipping west under the highest, namely, the Upper Ludlow and Downtonian of Sedgley. I am glad to see that conclusion confirmed by Mr. King's record of the character of the floor under the Bilston and Tipton Basin. This is what I have taught for many years. Mr. King, however, shows that the Russell Hall Fault, which I had assumed to have affected only the Coal-Measures, was to a much greater extent a pre-Coal-Measure fault, having a maximum throw of 1,300 feet already before Coal-Measure time, and a further dislocation of 826 feet after Thick Coal time. This, I suppose, is well known in mining circles. It is also of great interest to learn that the Bentley Fault is a pre-Coal-Measure dislocation, and one is inclined to agree with Mr. King, in view of the well-known magnitude of the Swinford Fault and its parallelism with the Russell Hall Fault, that this probably also is a pre-Coal-Measure as well as a post-Coal-Measure dislocation.

In one respect I do not think that Mr. King has made out a good case. In his plexographic map the sharp Dudley to Sedgley Hills, namely, Dudley Castle Hill, the Wren's Nest, and Hurst and Cinder Hills, are only of moderate elevation; moreover, in the map accompanying the present paper the areas are all represented as being, already in Lower Carboniferous time, upfolded and denuded almost as now, so as to expose Wenlock Limestone cores on these sharp folds, and he argues for the sharp upfolding of his Lickey to Sedgley *arête* already in Lower Carboniferous time. I have followed as far as I can Mr. King's argument, but I am not satisfied with the evidence. The oldest Silurian rocks in contact with the Coal-Measures around these hills are Lower Ludlow, whilst at Sedgley the Coal-Measures rest on the Upper Ludlow. Only in one place, namely, at Pennant Hill Pit, and that far to the south-east, is it evident

that the base is on Wenlock. If the same relations of Coal-Measures to Silurian obtained in the areas where the Coal-Measure base is removed by denudation, as at the junction outside, a much gentler folding, perhaps very little, would be required to have taken place before Coal-Measure time. Is not the close parallelism of dip between the Coal-Measures and the Silurian a strong argument against folding before Coal-Measure time?

In one respect Mr. King seems to me to go beyond the evidence and beyond probability. He claims exposure of the pre-Cambrian at the Lickeys already in Lower Carboniferous time. But the junction between them and the Cambrian quartzite is probably a fault, whilst neither the Silurian base nor the Coal-Measure base there contain appreciable Uriconian fragments. Such fragments are first common in the Espleys of the Old Hill Marls, and attain a maximum in the Clent breccias. But this is only a minor detail, and does not affect Mr. King's main argument.

What conspicuously emerges from Mr. King's work is the dominance of the N.N.E. strike and the W.N.W. dip in the rocks, and the marked shift of these by the Russell Hall Fault, and probably also the Swinford Fault. The history and development of the structure of the coalfield in post-Coal-Measure time is a subject of great interest, but naturally is only slightly referred to by Mr. King, who attributes much more of the structure to Lower Carboniferous time than some of us expected.

Mr. King's discussion of the character of the pebbles in the different conglomerates and their rate of gradation laterally into sand, with the deductions based on these data, are admirable, and it is a type of work which he has made particularly his own. His description of the gradation of these pebbles enables us to realize the expanse of those Mercian Highlands in the south which loom large and come very near in Permian breccia time. The author's deduction of north and south ridges extending from them along the Stour and Blythe Valleys is interesting, but we must await fuller evidence.

Mr. King touched lightly on the question of Armorican (or east and west) faults and Malvernian (or north and south) folds. The former are of special interest to the colliery-owner. The latter are of more general interest: those Mr. King referred to as being along the Stour and the Blythe are problematical: but we can group under such a term as "Malvernian folds" the Dudley Castle Hill, the Wren's Nest, the Cinder Hill, and Hurst Hill. These are anticlines of Silurian with troughs between them. Mr. King attributes them mainly to Lower Carboniferous time, but in this I think he is mistaken. The Netherton Anticline he includes in his Caledonian folds, and there also doubtless he would attribute a great deal of the folding to pre-Coal-Measure time—that is, he would claim perhaps that the Silurian below the Coal-Measures is considerably more folded than the Coal-Measures themselves. I should like to ask Mr. King whether it is not true that all those folds are steeper on the eastern side than on the western side, and are similarly sharp folds, with faults often running through their axes, and whether they may not be of the same age and were probably formed under similar conditions. Not improbably they may be connected in age with the intrusion of the Rowley dolerite, and the other similar intrusions scattered over the coalfield. What conditions must have obtained for the formation of these sharp folds with their longitudinal faults? Judging from their form, they were probably quite superficial in their origin—that is, so near to the surface that the strata could easily break

out. If this be true, we must attribute them to a time when South Staffordshire was not deeply buried. The continuation of the Dudley to Sedgley Hills is seen in the intrusion of the Rowley dolerite, and intrusion also occurs in the core of the Netherton Anticline. Thus it seems not unlikely that the uplift of those folds is connected in date with the intrusion of the dolerite. That happens to fit in with each of the ages which have been suggested for the intrusion, namely, late Coal-Measure and Tertiary. Of the two, the first seems much the more likely, as no such folds affect the Trias. There would be less cover than in later times, and I ask whether those folds and intrusions do not much more probably belong to late Coal-Measure time, and whether they may not be connected in origin with one or more of the Upper Coal-Measure conglomerates. Some of the Halesowen conglomerates certainly contain a considerable if not a preponderating bulk of Coal-Measure pebbles, Espley rock, clay-ironstone, coal, and Coal-Measure sandstone.

Another and related question of great interest may not improbably be answered by a careful analysis of the shaft section in Mr. King's possession, and I should like to ask whether in view of the very numerous conglomerates within the Coal-Measures he has seen evidence for any widespread unconformity—say, at the base of the Old Hill marls or the base of the Halesowen sandstone.

In conclusion, I am sure Mr. King will not regard this contribution to the discussion as carping criticism, since no one has a greater admiration than I for his work.

Mr. S. L. Thacker (Walsall): I have been wondering during the discussion what is the relationship in time between the Netherton Anticline and the upheaval of the intrusive basalts, and the intrusion of the sheets of intrusive trap-rock in the Essington area. I have seen a good deal of the trap-rock, and I have always been impressed with the extraordinary conditions which must have obtained for it to be able to force its way in such thin bands for such a long distance. We are almost forced to the conclusion that there could not be very much cover at that time, and that the Coal-Measures themselves must then have been very different from their present consolidated condition.

Another very interesting area is the Walsall Silurian area. I do not know whether Mr. Wickham King has any information as to its extension on the eastern side of the Boundary Fault. There again, the question arises of the relationship between the upheaval of the Silurian area and the dislocation of the Eastern Fault, which apparently extended to the Red Measures. In regard to the Walsall area, I should like to know whether there is any data or as to how far evidence has been obtained as to whether the Coal-Measures repose against the Silurian strata, or whether they are faulted against it. Such evidence would be of great value in determining the time of the upheaval, or whether it existed as a bank against which the Coal-Measures were originally deposited.

Mr. T. G. Bocking (Birmingham): In regard to the question raised by Mr. Thacker, I came into the district just when the Sandwell Park Colliery workings in that direction were coming to an end for the time being. But I always understood that the formation was more or less in the nature of a bank, with the Coal-Measures against it, and not in the nature of faulting.

In the paper given by Mr. H. Ridsdale some time ago he appeared to condemn the southern part of the area between Warwickshire and

Staffordshire, whereas Mr. Wickham King seems to give it a reprieve.

As one interested in the district, I am greatly pleased to hear my own opinion confirmed by Mr. King that, in the Blythe Valley, there may be workable Coal-Measures at no very great depth. I suggest to Mr. King that as the paper is so highly technical, a general glossary might make it more widely useful.

Mr. J. Southan (Tipton): It would be interesting to know at what time the intrusive or trap-rock was laid down, and the conditions under which the laying-down took place. If the intrusion was simultaneous with the volcanic disturbances which probably caused the faulting of the South Staffordshire Coalfield, would not that upset the theory that the Russell Hall and Bentley Faults were pre-Coal-Measure faults?

Mr. W. Wickham King (Stourbridge): I thank the members for their kind reception of this paper, and Prof. Boulton for his valuable contribution, which coincides with my views. The Mercian Highlands that did exist to the south-east of the South Midland Coalfields were arranged much like the Bernese Oberland, which has its greatest length from W.S.W. to E.N.E., and has its highest crests, of the Lauteraarhorn, Finsteraarhorn, and Aletschorn, and their parallel deep valleys, from S.S.E. to N.N.W. The pre-Coal-Measure denudation in the Dudley—Sedgley district, though less than to the south-east, was immense, for the Gornal grits, and the thin coal and clays below, constituting the lowest Coal-Measures there, rest on a floor composed of the Wenlock to the Ledbury Fish Band of the Downtonian. This should be compared with the sequence set out on page 152.

On the Walsall plateau the lowest Coal-Measures rest on, *inter alia*, the Lower Wenlock and Llandovery, and so the Eastern Boundary Fault may be partly due to pre-Coal-Measure movements, as at Langley to the south. The constitution of the floor (see Fig. 3, page 159) in the south-eastern parts of the Charnian Swinford *arête* point to pre-Coal-Measure movements, during which this ridge would be partially formed; whilst further north at Baggeridge there is very little difference in the thickness of the Downtonian on the two sides of the western faults there. The greatest uplift was in the south-eastern parts of the coalfield.

Prof. Boulton and Dr. Wills allude to an unpublished map I made some years ago, which the latter, following Dr. Boswell, suggests should be called an Isopachytes map, depicting lines joining points where equal thicknesses of beds occur. It is based on the thickness of the Coal-Measures below the top of the Thick Coal, and affords further information as to the Caledonian and Charnian folds then existing. These beds are thickest (420 feet) to the north-west in the Bilston syncline (near 13 on Fig. 3) and thinnest (24 feet) to the south-east at Moat Farm, Langley (65 on Fig. 3). Their thickness is on the south-western edge of the Walsall plateau (56B) 260 feet, on the Sedgley—Dudley ridge 200 to 235 feet, and in the intervening syncline 355 feet. Near the south-eastern parts of the Swinford *arête* their thickness is 300-380 feet, which is an additional proof that this *arête* was in early Coal-Measure time at a lower level than the Rowley and Bentley Charnian *arêtes*, for at 65 on Fig. 3 these beds are only 24 feet thick. This map shows by means of the variation of the thickness of these beds where the basins and higher ridges then existed; and, furthermore, supports the views of Prof. Boulton and Dr. Wills and my inference, founded chiefly on the other data already given, that whilst on the South Staffordshire arch the beds below

the top of the Thick Coal were nil to 420 feet, yet they were thicker and included the underlying highest Avonians in the still deeper basins to the south-west, north-west, and north-east of this arch.

The definition of the Downtonian (see note on page 152) is that given by the Geological Surveyors in Scotland. The dip of the Coal-Measures, *inter se*, and of the pre-Carboniferous is often the same, and, sometimes, fallacious. The false-bedded Basal Coal-Measures exposed at Saltwells are on this point instructive. My specimens of Llandovery beach rocks made up of Cambrian and Uriconian materials (some 1 inch square) prove that the lowest Silurians of the district were laid down across the Cambrian and Uriconian. The present Lickey ridge is only a fragment of the extensive but now buried ridges existing in that locality during early and late Carboniferous time, and from whence were derived the Llandovery and Cambrian fragments so abundant in the lowest Carboniferous conglomerates laid down within a few miles to the north-west, and the pebbles of Uriconian which Jukes recognized and I find are so very common in the Espley beds embedded in the Old Hill marls and Halesowen sandstones of the Cradley Basin. The pit sections at the southern end of the Cradley Basin show that many bands of conglomerate exist there and die out to the north-west; but whether there is an unconformity below the Old Hill marls and the Halesowen sandstones or between the latter and the Keele beds are questions which I believe the Geological Survey are investigating. Sedimentation after Thick Coal time probably was irregular in the south-eastern parts of the coalfield, whilst to the north-west it continued uninterruptedly. The Rowley basalt occurs 700 feet above the Thick Coal or at lower zones, but its age is at present unknown.

The South Staffordshire arch is steep on its eastern and western sides. The Wren's Nest to Hurst Hill trend-line is very steep on its eastern side, but the steepest face is at Ellowes Park on the western side of this arch, where the fold is slightly overturned. The Rowley ridge between Coombe Wood and Dixon's Green, and the parallel Swinford ridge, are markedly steepest on their western sides, and in this accord with the Malvern Hills and Trimpley, where the thrust is from the east towards the west.

I would cordially co-operate in the reproduction of my plexographic map and model, which visualize the actual, not theoretical, structure resulting from the movements described, and, furthermore, as pointed out when I read this paper, the beautiful arrangement of the rock waves, and the dying-out along their trend of the faults developed along the line that divide the steepest limb of each arch from its anterior trough.

In conclusion, I owe a debt of gratitude to the mining engineers and colliery proprietors of South Staffordshire, as without their help I could not possibly have accomplished this piece of work. For that reason I determined to make the first publication of the results before the Institute connected with these generous and broad-minded colleagues.

THE MIDLAND INSTITUTE OF MINING, CIVIL, AND MECHANICAL ENGINEERS.

GENERAL MEETING,
HELD IN THE MAPPIN HALL OF THE UNIVERSITY OF SHEFFIELD,
DECEMBER 8TH, 1921.

LT.-COL. HARRY RHODES, PRESIDENT, IN THE CHAIR.

MEMOIR OF THE LATE SIR WILLIAM GARFORTH, LL.D., F.G.S., M.INST.C.E., J.P., ETC.

BY W. D. LLOYD.

Sir William Edward Garforth died at his residence, Snydale Hall, near Pontefract, on Saturday, October 1st, 1921, aged 75 years. He was born at Dukinfield, Cheshire, in 1845, and was the second son of the late William Garforth, J.P., owner of the Dukinfield Ironworks and Lordsfield Colliery, near Ashton-under-Lyne, and grandson of the late Mr. John Garforth, a descendant of an old Yorkshire family, who established the before-mentioned works in 1825. At these works riveted girders from the designs of Mr. Robert Stephenson and Sir William Fairbairn were made for two of the first railway-bridges erected, as also a large portion of the wrought-iron tubular bridge over the Menai Straits.

Sir William was educated at Denmark Hill, and received his training in the profession of a mining engineer in Lord Stamford's survey office and at his father's colliery and works. He obtained his Colliery Manager's Certificate of Competency in 1875, and in 1879 he was appointed Agent to Messrs. Pope & Pearson's Collieries, Normanton, of which company he later became Managing Director and afterwards Chairman.

He was elected a member of the Manchester Geological Society in 1873 and of the Midland Institute in 1880. He was President of the Midland Institute for the years 1892-1893 and 1893-1894, and President of The Institution of Mining Engineers for the three years 1911-1912 to 1913-1914. It was largely owing to his initiative during his Presidency that arrangements were made which resulted in the Institution receiving its Royal Charter in February, 1915. From 1878 to the time of his decease, he contributed numerous papers to the *Transactions* on matters relating to mining.

He was President of the Mining Association of Great Britain during 1907 and 1908; Chairman of the Standing Committee on Mining set up by the Advisory Council for Scientific and Industrial Research; and was a Fellow of the Geological Society of London. He served on behalf of the Board of Trade as a Juror at the Brussels Exhibition in 1910, and was elected Vice-President of the Mining Section. He gave evidence before various Royal Commissions on matters affecting the safe working of

mines, namely, in 1891 "On the Danger of Coal-dust," in 1898 "On the Use of Electricity in Underground Works," in 1902 "On the Coal Supplies of the United Kingdom," and in 1907 "On Accidents in Mines."

On October 2nd, 1886, an explosion occurred in the Silkstone Seam at the Altofts Collieries, which were under Sir William's charge. This explosion, although it caused a regrettable loss of twenty-two lives, was turned, by his faculties for observation and deduction, into a blessing in disguise, as it was from the information he then obtained of the effect of stone-dust on a coal-dust explosion that he was led to propose the stone-dust remedy to prevent explosions of coal-dust. In his evidence before the Royal Commission on Explosions from Coal-dust in Mines on July 2nd, 1891, he suggested that experiments should be made on the different kinds of coal-dust and dirt-dust, and stated that he believed that "dirt-dust would be the means of preventing an explosion on some roads—more so than watering." It was not, however, until sixteen years later, after he had confirmed the recommendations made in 1891 in his evidence before the Royal Commission on Mines in March, 1907, that any real progress was made. He then showed how experiments on a large scale might be conducted, and subsequently having impressed on the Mining Association of Great Britain the advisability of such experiments, he was entrusted by that body with the conduct of the British Coal-dust Experiments, which were carried out at Altofts from 1908 to 1911. In May, 1908, he proved that without the presence of gas coal-dust was explosive, and so settled the controversy as to whether coal-dust *per se* was explosive. Thus ended a discussion that had been carried on for over thirty years. He then proceeded to put to the test his theory that fine stone-dust would extinguish the flame of an explosion. In July, 1908, he was able to demonstrate this fact, which was confirmed by later experiments at Altofts and Eskmeals. In September, 1908, he introduced the stone-dust remedy underground, and showed not only that it was easily and cheaply applied, but that by treating all coal-dust with stone-dust the possibility of an explosion could be reduced to a minimum at an inconsiderable cost and without introducing any additional danger to the health of the miners. The value of his discovery of the stone-dust remedy for preventing mine explosions has now been universally recognized. Regulations issued under the Coal Mines Act, 1911, came into force in January, 1921, making it compulsory in all mines which are not naturally wet throughout to treat all roads with incombustible dust so as to ensure that the dust always consists of a mixture containing not more than 50 per cent. of combustible matter. The mining community will always associate his name with this epoch-making discovery, which will make the tragedies of disastrous explosions a thing of the past, provided that the remedy is properly applied.

Sir William was one of the principal pioneers of machine-holing, and in 1893 introduced an improved type of deep undercutting machine. In mining questions his motto was always "safety first," and he was a strong advocate of using machine-holing combined with the longwall method of working. This combination of a straight face with a straight line of cut produced a straight line of break in the roof, which could easily be supported by a straight line of timber set systematically, and increased materially the safety of working. Other advantages were a lower cost of production and a higher yield of large coal.

In 1901, in order to test several forms of self-contained breathing-apparatus then on the market, he erected on the surface a gallery, made

to represent the damaged roadways of a mine, which could be filled with noxious fumes. This gallery was the first of its kind in this country or abroad, and formed a model from which the rescue-stations now established all over the country have been developed. He also devised a breathing-apparatus to suit his own idea that the control of the oxygen should be regulated automatically by the lungs of the wearer, and that the weight should be distributed as far as possible for the comfort of the wearer. In various competitions his design proved at least equal to any other form of apparatus then in use.

From the experience gained after the Altofts explosion, he drew up a code of "Suggested Rules for the Recovery of Coal-mines after Explosions," and these he presented to the Institution in a paper which he read in 1897.* These rules were subsequently revised by him and published in book form, and they have been taken as a basis for the rules adopted at various rescue-stations in this country and abroad.

He took a keen interest in mining education and research. He was Chairman of the Mining Advisory Committee of the Leeds University for many years, and Chairman of the Governors of the Normanton Grammar School and the Girls High School. The Normanton Technical School owes its existence and success largely to the interest taken by him in education.

Amongst other researches, Sir William extended the use of photography underground by the employment of concentrated incandescent electric light. He took a great interest in the application of the microscope in mining research, particularly in regard to coal-dust and stone-dust, and also for ascertaining the composition of coal-seams by means of exceedingly thin sections. He was an enthusiastic Mason, being initiated at Lodge Fidelity, Ashton-under-Lyne, and became Worshipful Master of that Lodge in 1872. After coming to Yorkshire, he joined Lodge Unanimity 154, Wakefield, and became Worshipful Master in 1891. He was made Provincial Grand Senior Warden in 1919, and received the honour of Grand Deacon of England in 1921.

He took an active share during the war on many Committees, and at the Diamond Coal Cutter Works, Wakefield, which belonged to him, the output of 18-pounder shrapnel shells reached 8,000 per week.

He was appointed a Magistrate for Cheshire in 1876, and for the West Riding of Yorkshire in 1892. He was Chairman of the Altofts Urban District Council for thirty-five years.

He received the honour of Knighthood in 1914, and the degree of LL.D. from the Universities of Birmingham and Leeds in 1912. He was awarded a Medal at the London Inventions Exhibition in 1885 for his invention of a firedamp detector. He received in 1907 the Greenwell Silver Medal from the North of England Institute of Mining and Mechanical Engineers, and the Fothergill Gold Medal from the Royal Society of Arts in 1910. In 1914 the first Medal of The Institution of Mining Engineers was awarded to him "For distinguished Services rendered to Mining Engineering," and in 1918 he received the Peake Medal from the Midland Institute.

His death has deprived the coal-mining industry of one of its most progressive leaders, and The Institution of Mining Engineers has lost one of its oldest and most valued members.

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* *Trans. Inst. M. E.*, 1897-1898, vol. xiv., page 495.

MEMOIR OF THE LATE PROF. FRANCIS EDWIN ARMSTRONG, M.Sc., Assoc.M.Inst.C.E., Etc.

By Prof. R. V. WHEELER, D.Sc.

The late Prof. Armstrong was born in 1879, and was the son of the late Rev. Richard Acland Armstrong, Unitarian Minister at Liverpool. Educated at Giggleswick School and Liverpool University, he held the degrees of M.Sc. (Vict.) and M.Eng. (Liverpool), and was an Associate Member of The Institution of Civil Engineers. On leaving College, he obtained work at the Westinghouse Company's electrical works. In September, 1910, he was articled pupil to Mr. Arnold Lupton, mining engineer and Director of the Tinsley Park Colliery, Sheffield, then residing at Leeds, with whom he had varied experience in mining and electrical work. In 1903 he became associated with Mr. J. H. W. Laverick, Manager of the Riddings Colliery, Alfreton, Derbyshire, and subsequently his assistant at the Newdigate Colliery, Warwickshire. In 1906 he was sent by Sir Ernest Cassel to take charge of his coal-mines in Mexico. He also reported on coal-mines in British Columbia. Later, he rejoined Mr. Laverick, who was then in charge of the Tinsley Park Colliery, Sheffield, and subsequently obtained an appointment as Assistant General Manager at the Askern Main Colliery, Doncaster.

Prof. Armstrong was elected to the Chair of Mining at Sheffield University in 1913, which appointment he held until his death on October 28th, 1921. Soon after the outbreak of war in 1914, he volunteered for non-military service in France with the Friends' Ambulance Unit of the British Red Cross Society, taking his motor-car as near to the front line as was possible and rendering medical services. In 1917 he was sent for by Sir Richard Redmayne to assist in the control of British coal-mines, and was made head of the Labour and Wages Section of the Production Branch of the Coal Control until his return to Sheffield University after the signing of the Armistice.

A man of wide interests and sympathies, Prof. Armstrong endeared himself to all with whom he came into contact. His high scientific attainments, together with his mastery of the practical details of coal-mining, combined to render his Department at Sheffield University, which grew rapidly under his administration, a great success. He was respected and admired by his students, with whom he was very popular, and in whom he took a keen personal interest, and was held in high esteem by his colleagues. He was a member of the Miners' Lamps Committee, appointed by the Government to investigate and improve the safety and efficiency of lamps for use in coal-mines, and here, as in his University work, his colleagues placed great reliance on his quick intelligence, which, combined with a capacity for painstaking effort, rendered him an invaluable member of the Committee, who soon learned that when Prof. Armstrong promised to do anything (and he was not chary of granting his services), it was done quickly and well.

In concluding this memoir I would like to place on record my personal sorrow and dismay at Prof. Armstrong's death. I must always owe him a debt of gratitude for the encouragement and self-sacrificing help that

he gave me, a newcomer to Sheffield University. Such progress as has attended the development of the Department of which I have charge is due mainly to Prof. Armstrong's zeal for the welfare of the University.

The PRESIDENT (Lt-Col. Harry Rhodes) moved a vote of condolence with the relatives of the late Prof. Armstrong, which was carried unanimously, the members standing.

ELECTION OF MEMBERS.

The following gentlemen were elected members of the Institute :—

MEMBER—

Mr. EDWARD BOYES JOHNSTON, Chief Surveyor, Bargoed Colliery, Bargoed, Cardiff.

ASSOCIATE MEMBERS—

Mr. WILLIAM BIRCH, Mining Student, 36, Colenso Grove, Leeds.

Mr. HERBERT WARD, Colliery Under-manager, 2, McLaren Crescent, Maltby, Rotherham.

ASSOCIATES—

Mr. WILLIAM HUNTER, Mining Student, 8, Brook Street, Fryston, Castleford.

Mr. T. J. WHETTON, Mining Student, 17, North Street, Fryston, Castleford.

Mr. L. RAWLINSON, 7, Glen Mount, Tingley Common, Morley, Leeds.

STUDENTS—

Mr. J. DAS, Mining Student, 15, Hessle View, Hyde Park, Leeds.

Mr. G. HURST, Mining Student, Albert Hotel, Albert Road, Retford.

Mr. A. WRIGHT, Mining Student, 25, Saville Road, Halifax.

TRANSFERS FROM ASSOCIATE MEMBER TO MEMBER—

Mr. E. A. MOORHOUSE, Colliery Engineer, Lowmoor Road, Kirkby-in-Ashfield, Nottingham.

Mr. A. S. DALLAS, Chief Surveyor, 32, Darfield Main, Wombwell, Barnsley.

Mr. C. W. WINFIELD, Colliery Manager, Kautapahari Collieries, Sitarampur, India.

TRANSFERS FROM STUDENT TO ASSOCIATE—

Mr. T. G. BAKER, Mining Student, Oakwood Grange, Rotherham.

Mr. S. C. BROWN, Mining Student, Heather Bank, Albany Walk, Ilkley.

THE METERING OF LARGE VOLUMES OF AIR AND GAS BY MEANS OF THE VENTURI TUBE.

By JOHN L. HODGSON.

I propose in the following paper to give a short account of the application of the Venturi meter for the measurement of large volumes of air and gas.

As is well known, the Venturi tube (Fig. 1) consists of two cone pieces connected by a throat section. The difference of pressure which exists when a flow is passing between the points *U* and *T* is used as the basis of the measurement. The function of the converging upstream cone is to guide the stream-lines evenly to the throat, while that of the gradually diverging downstream cone is to enable the high velocity at the throat to be brought back to the original low velocity on the upstream side of the tube with the minimum loss of pressure in eddies. In a carefully-constructed Venturi tube, the loss of pressure due to its insertion is only about one-eighth of the difference of pressure which is produced between the points *U* and *T*.

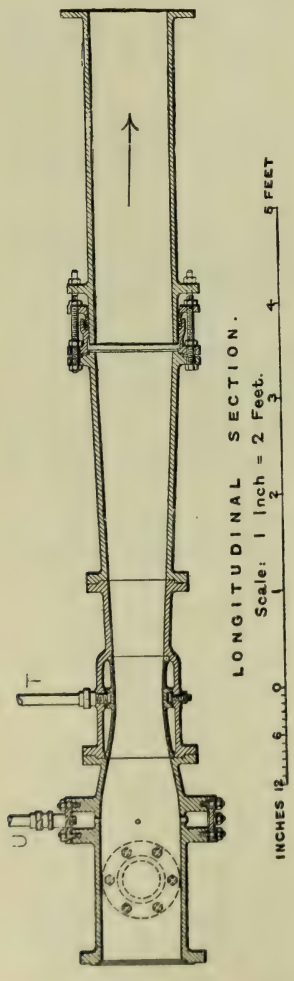


Fig. 1.—The Venturi Tube.

The standard Venturi tube shown in Fig. 1 can be modified in various ways—for example, as in the Orivent tube shown in Fig. 2. Here the upstream cone is practically done away with, and the downstream cone is not continued to the full diameter of the pipe. In such a tube the loss of pressure is about one-sixth of the difference of pressure produced between the points *U* and *T*.

In all cases of air or gas measurement it is desirable to make the difference of pressure between the points *U* and *T* as large as possible, in order to have adequate power to operate the recording instruments; and, on the other hand, to make the pressure loss due to the insertion of the difference of pressure-producing device as small as possible, in order to keep down the expense of running the compressors, fans, or exhaustors. The Venturi tube and the Orivent tube enable both of these conditions to be reasonably fulfilled.

The Venturi tube has the further advantage for gas measurement

that when measuring dirty gas it causes less deposit from the gas than any other form of differential pressure-producing device. This is because of its smooth contour, which reduces the formation of eddies, and hence the amount of deposit, to the minimum. Further, the higher velocity of the gas at the Venturi throat tends to sweep out any deposit that may have formed.

Fig. 3 shows a typical gas Venturi tube. It will be noticed that it is installed vertically, with the flow descending, so that any deposit which may tend to collect falls through the tube. In order to prevent the deposition of tar, naphthaline, or other condensable substances on the Venturi throat, this, in the case of Venturi tubes measuring dirty gas, is kept at a slightly higher temperature (say, 5° Fahr.) than that of the gas passing through by means of a steam-coil. The throat sections of the gas Venturi tubes are also made so that they can be easily swung out of the pipe-line for inspection or cleaning. The air Venturi tubes, on the other hand, are provided with a hand-hole through which the throat section can be inspected and cleaned. In the case of air Venturi tubes and gas Venturi tubes measuring town gas (which have their throats heated during the winter months in order to prevent the deposition of naphthaline), it is not found that any deposit whatever occurs. In

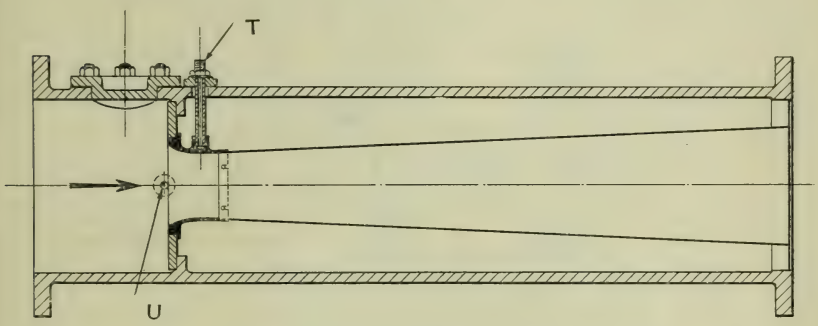


Fig. 2.—The Orivent Tube.

the case, however, of Venturi tubes measuring producer or other unpurified gas, it may be found necessary to clean out the throat of the tube once every 12 hours. A deposit in the throat causes too high a differential pressure to be obtained, and this makes the meter read fast.

Turning now to some of the recorders which my firm and I have developed for obtaining a counter or diagram record of the flow passing through the Venturi tube, the simplest of these is that shown in Fig. 4. It consists of an oil-sealed bell, which simply records on a diagram the difference of pressure produced by the Venturi tube. The upstream pressure is brought to the underside of the bell and the motion is transmitted to the pen arm through the gland *G*. If the pressure, temperature, and specific gravity of the gas are constant, or if their variations are allowed for by means of tabular numbers, this simple type of recorder is capable of giving readings that are accurate to within plus or minus 1 per cent. down to about one-fifth of the maximum flow for which the Venturi tube is designed. It will be seen on reference to the figure that below, say, one-tenth of full flow it would be difficult to obtain accurate readings on the diagram, even supposing that the pen had been adjusted correctly to zero and that there was no friction in the instrument. If the gas is saturated with or contains large quantities of water-vapour, it is desirable to cool it to below 120° Fahr. before

measurement. Assuming that the gas is saturated with water-vapour, the amount to be deducted from the meter readings (since the meter

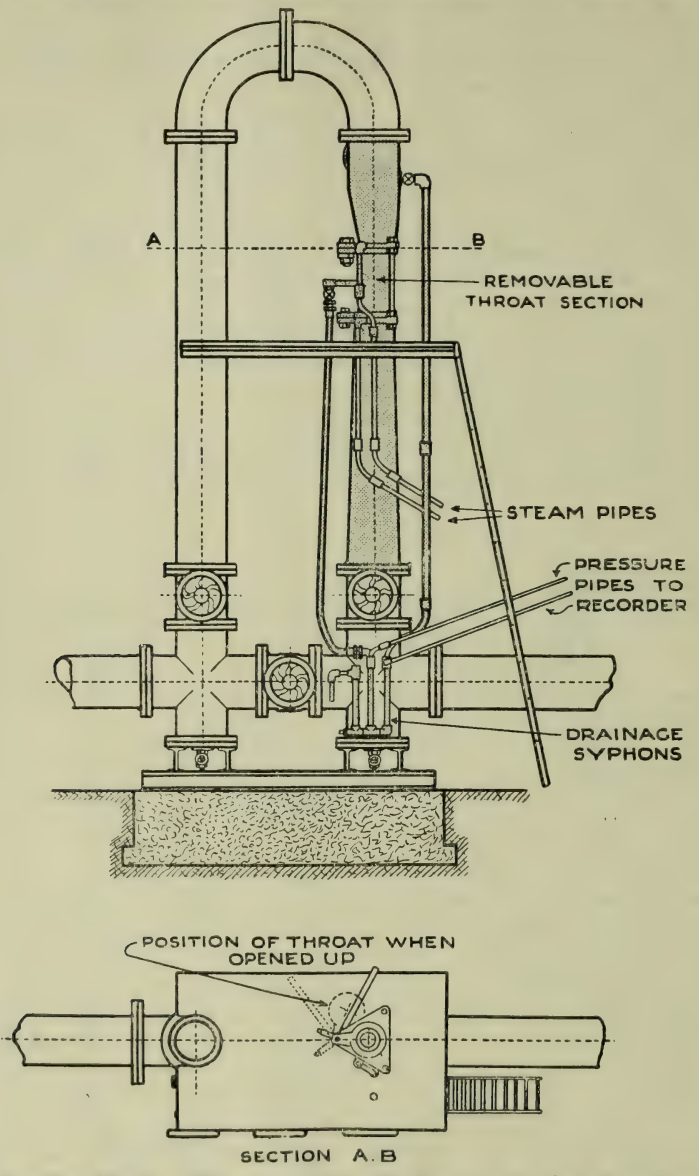


Fig. 3.—The Venturi Tube installed Vertically for Gas Measurement.

registers the total volume of gas and water-vapour passing) is—

$$\left\{\frac{p_1'}{p_1} \times 100\right\} \text{ per cent., where } p_1 = \text{pressure of the gas, in pounds}$$

per square inch (absolute), and p_1' = pressure of the water-vapour, in pounds per square inch, at $t°$ Fahr.

i.e., 1·7 per cent. at 60° Fahr.
4·7 „ „ 90° „
11·5 „ „ 120° „
25·2 „ „ 150° „ and so on.

It will be seen that at temperatures above 120° Fahr. the correction to be applied is considerable; and if it is not certain whether the gas is completely saturated with water-vapour or not, quite appreciable errors may be made in estimating the amount to be deducted from the meter reading. The presence of free water-particles in the gas does not cause any very great error in the reading. Thus, if the gas contains 5 per cent. (by weight) of water-particles, the error in the meter reading is only $2\frac{1}{2}$ per cent.

In gas measurement the variations of temperature and pressure are usually small, and so can be allowed for by means of tabular numbers without causing any appreciable error in the total quantity recorded. A variation of 10° Fahr. in the temperature, or 8 inches of water-gauge in the pressure, causes an error of only about 1 per cent.

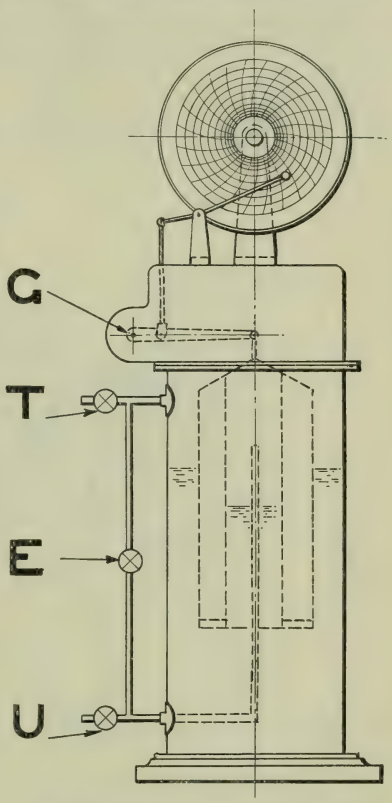


Fig. 4.—The "District" Type Recorder.

The simple type of meter shown in Fig. 4 can be made to record by counter as well as diameter. This is done as follows:—A cam *C* (Fig. 5) is caused to rotate once every 4 minutes by means of a pendulum-driven clock, and an arm *A* carrying the spherical contact-piece *S* is raised or lowered by the connecting-rod *R*, which is actuated by the bell which measures the difference of pressure between the points *U* and *T* on the Venturi tube. On the same spindle as the cam is the toothed wheel *W*, which drives the counter-wheel *T* through the wheel *X* and pinion *Y*. When the contact-piece *S* is out of contact with the surface of the cam, the rocking-frame *F*, which carries the wheel *X* and the pinion *Y*, moves forward until it reaches the stop *B*, being pulled by the spring *G*, so that the wheel *X* engages with the wheel *W* and transmits its motion to the counter train *T* through the pinion *Y*. When the cam moves round so that the contact-piece *S* is pushed back by it, the wheel *X* is thrown out of gear with the wheel *W*, and the counter ceases to register. By suitably shaping the cam, any desired amount may be added to the counter reading during each revolution of the cam for any specified position of the arm *A*. In this way the rates of flow shown on the diagram are integrated, and a counter record of the flow is obtained.

The mechanism just described has been so designed that only the least possible force is required to move the arm *A*, while an absolutely positive mechanism is employed to obtain the counter record. This is altogether preferable to any planimeter type of mechanism, which may easily give erroneous readings owing to friction in the light-running train.

As in certain cases—for example, when measuring ordinary town gas—the specific gravity of the gas relative to air at the same temperature

and pressure may vary considerably, it has been found necessary to develop a station gas-meter that automatically corrects the record for such variations. A diagram of this meter is shown in Fig. 6. In this meter, instead of driving the integrating mechanism—in the diagram a cam, feeler, and rachet-and-pawl device *C*, *G*, *F*, *R* is shown—at a uniform speed by means of a clock, it is driven at a speed inversely proportional to the square-root of the specific gravity by a small wet meter *W*, which measures the volume of gas escaping to the atmosphere through an orific *O*, across which a constant difference of pressure is maintained by means of a regulating-valve *RV*. The counter reading is thus made proportional to the square-root of the difference of pressure across the Venturi tube (this is determined by the position of the cam *C*, which is moved by the bell *B*, Fig. 6), divided by the square-root of the specific gravity of the gas (this is determined by the speed of the wet gas-meter *W*).

It will be seen on reference to the Venturi discharge equation (Appendix I.) that in this way the counter has been made to register the amount proportional to the volume passed.

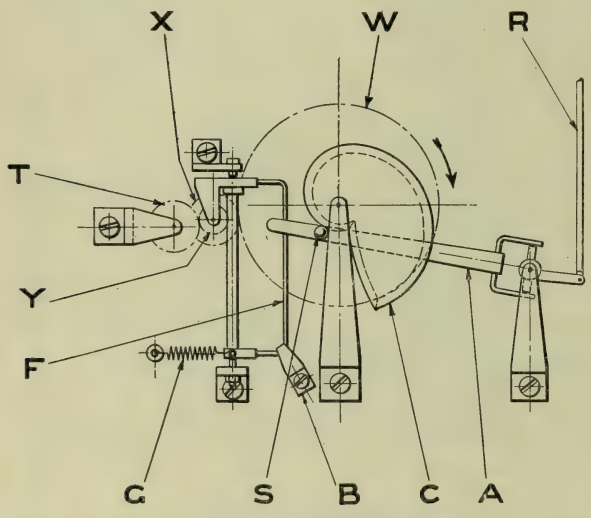


FIG. 5.—DIAGRAM OF THE INTEGRATING MECHANISM OF THE VENTURI GAS-METER.

The diagram record of the flow is obtained directly from the motion of the bell *B*, which measures the difference of pressure across the Venturi tube, and therefore is not corrected for variations in the specific gravity of the gas. It is the counter record only which is so corrected. A photograph of the meter is shown in Fig. 7.

A special feature of meters of the Venturi type is that their accuracy may readily be checked at any time *in situ*. All that it is necessary to do in the case of the meter shown in Fig. 4 is to see that the Venturi throat is clean, that there is no obstruction in the pressure-pipes, and that when a given difference of pressure is applied the pen moves the correct amount. In the case of the meter shown in Fig. 6, it is necessary, in addition, to test the specific gravity of the gas (by means of a specific-gravity bell), in order to determine whether the wet gas-meter *W* is rotating at the correct speed. In the case of both these meters the pressure-pipes must be of reasonable diameter, be laid at a sufficient slope to drain, and be provided with drainage syphons at their lowest points.

Since the meter shown in Fig. 6 is designed to register the actual volume of gas passed, its readings should agree with those of the drum type of station gas-meter. The table given in Appendix II. shows the results of a typical month's test, when such a meter was placed in series with a drum type of station meter. It will be seen that over the month

during which observation was continued the Venturi meter registered 0·6 per cent. more than the station meter, and that the difference between the two meters in no case exceeded 1·5 per cent.

If it be desired to obtain an indication only of the rate of flow, the curved-tube manometer illustrated in Fig. 3 of my paper of January 22nd, 1921, may be used.*

When measuring large gas-mains the Venturi tube may be placed horizontally, as the throat is then so large that a given amount of deposit causes but little error. If it be decided to install such a Venturi tube when the pipe-line is being planned out, very little additional expense is involved, as it is only necessary to substitute two wrought-iron cone-pieces and a cast-iron throat for a given length of straight piping.

In concluding this paper, a few notes on the history of the Venturi tube may be of interest.

The fact that a large part of the difference of pressure created by a nozzle could be recovered by means of a diverging cone has been known

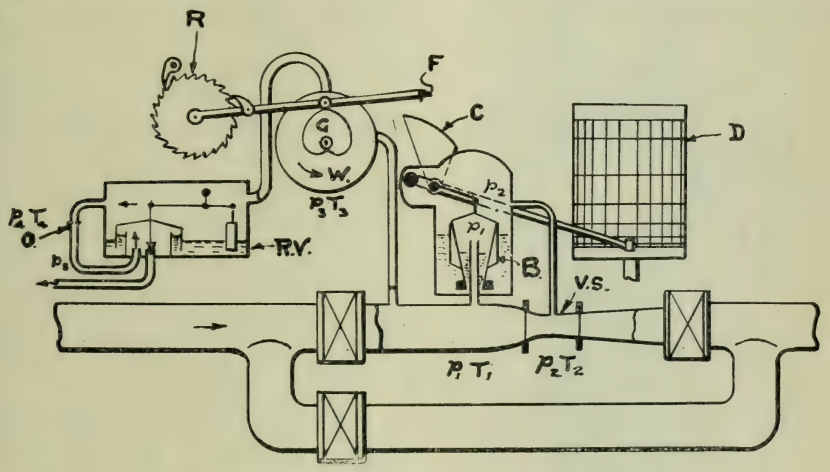


FIG. 6.—DIAGRAM OF THE VENTURI "STATION" GAS-METER.

since Roman times. The theory underlying the phenomenon was first investigated by the Italian physicist Venturi during some hydraulic experiments which he made at Modena in 1791. The first to realize that the difference of suction between the upstream and the throat of such an arrangement could be used to measure the flow passing was M. Bourdon, and about 1880 he used this principle to measure the velocity of the air-currents in the passages of certain of the French mines†. Then, about 1887 Mr. Clemens Herschel,* an American engineer, adopted Bourdon's air-measuring device for the measurement of large volumes of water. Using as a basis the theoretical work of Venturi, Torrecelli, and Dubaut, he developed an approximate theory of the Venturi water-meter, which is still valuable. He also constructed and tested several large water Venturi tubes, and in doing this discovered and overcame many of the practical difficulties (such as the tendency of air to collect in the pressure-pipes) which stood in the way of making the Venturi tube a successful and practicable water-measuring device. The results of the few tests that he made seemed to show that for the tubes

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 273.

† *Comptes Rendus, Société de l'Industrie Minérale*, 1882.

with which he experimented the simple square-root law held only within comparatively narrow limits, and it fell to my firm to calibrate carefully the Venturi tube over a wide range of flows, and to determine the best contours for the tube.

The first recording and integrating mechanisms for use in connexion with the Venturi tube were designed by Mr. Connet, of the Builders' Iron Foundry, United States of America, and by Mr. J. F. Grout, of Messrs. George Kent, Limited, Luton.

In 1907 I was asked to design meters for the Victoria Falls and Transvaal Power Company (Witswaterand), that would record by counter the energy required to compress air from mean atmospheric pressure and temperature to the temperature and pressure at which it was to be delivered to the consumer. I designed, and Messrs. Kent, Limited, constructed, two sets of air-meters for this purpose, one of which was used by the supply company and the other by the consumers. I used the Venturi tube as the basis of the supply-company's meters, and in connexion with this work the theory of the meter was very much elaborated, and careful tests were made as to the coefficient of discharge.* This work has been carried on by Messrs. Kent, Limited, since that date, and thousands of Venturi tubes have been made and calibrated.

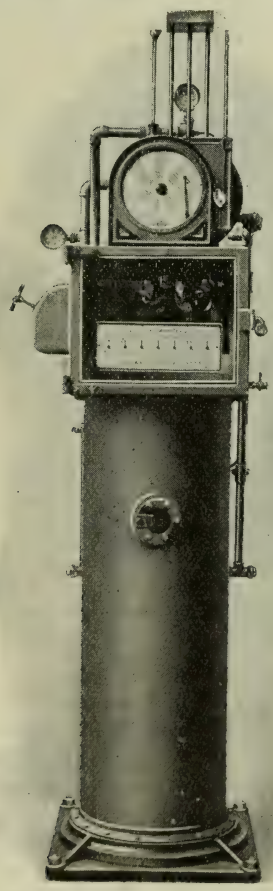


FIG. 7.—PHOTOGRAPH OF THE VENTURI "STATION" GAS-METER.

Figs. 8 and 9 show the main features of the Venturi air-recorder which I designed for the Victoria Falls and the Transvaal Power Company. It will be noticed that the difference of pressure between the upstream and the throat of the Venturi tube is measured by an inverted bell immersed in an oil-seal and supported by a float, of peculiar shape, immersed in mercury. The throat pressure is caused to act on the inside of the bell, and the upstream pressure on the outside. An increase in the flow thus causes the bell to descend, and the peculiar shape of the float, the buoyancy of which balances the difference of pressure, causes a very much larger motion at the smaller pressure differences than at the higher ones. In this way the difficulty that the flow varies as the square-root of the Venturi head is overcome, as although at one-tenth of full flow the difference of pressure available to produce the motion is only one-hundredth of the difference of pressure available at full flow, the shaped float gives so sensitive an arrangement that actually a larger amount of move-

* See *Minutes Procs. Inst. C. E.*, 1916-1917, vol. cciv., pages 123-134.

ment is obtained for a given change in the flow at the small flows than at the higher ones.

In the particular meter illustrated, only variations in the pressure of the air and in the difference of pressure across the Venturi tube were taken into account in computing the energy required to compress the weight of air delivered to the delivery pressure. The counter reading of the meter was obtained as follows :—The difference of pressure across the Venturi tube was measured by means of the bell shown in Fig. 8. The pressure of the air was measured by means of the pressure diaphragms shown in Fig. 9. By means of the cams shown in this latter figure, motions were obtained on the central or differential-gear spindle which were proportional to the logarithms of the functions of the pressure and the difference of pressure which it was desired to multiply together. A motion proportional to the sum of these logarithms was obtained by adding the motion on a differential gear, so that a motion proportional to the logarithm of the desired product was obtained on the anti-logarithm cam. The function of this cam was to convert the motion so obtained into the motion proportional to the product required. The motion thus obtained was caused to actuate a clock-driven integrating mechanism similar in principle to that shown in Fig. 5.

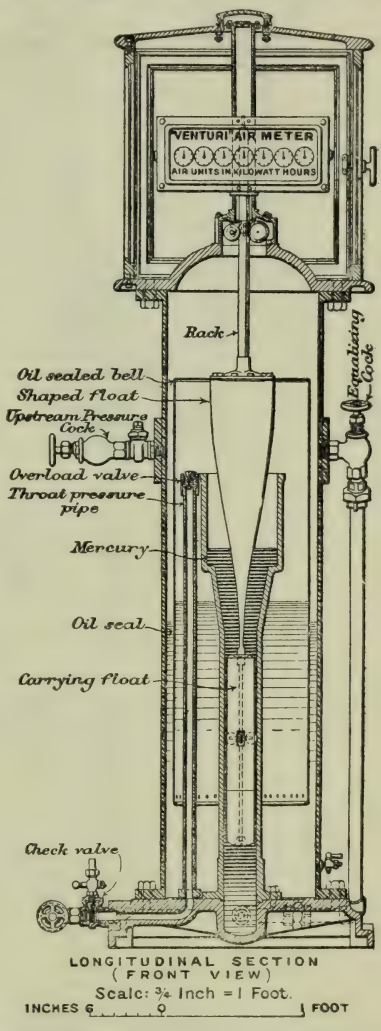


FIG. 8.—THE BELL OF THE VICTORIA FALLS AND TRANSVAAL POWER COMPANY'S METERS.

These meters were installed in 1911, and have been in successful operation ever since. As they are too expensive for general use in mining work, the mercury type of air-meter shown in Fig. 8 of my paper of January 22nd, 1921,* is now usually used in connexion with the Venturi tube or the Orivent tube for measuring the flow of compressed air. This meter registers the number of cubic feet of free air passed, as is generally desired by English engineers. The basis of measurement adopted by the Victoria Falls and Transvaal Power Company twelve years ago was, however, a much more useful one, as neither the user nor the producer of the air is particularly interested in the actual number of cubic feet delivered, but rather in the energy in the air delivered. If the air-meters are designed to measure the energy in the air, their readings are directly comparable with those of electricity meters; and

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 277.

if the amount of coal supplied to the boilers which provide the steam which operates the compressors is also debited on a energy basis, the economy of the whole plant can be much more easily checked (seeing that everything is measured in terms of energy) than is the case when the coal

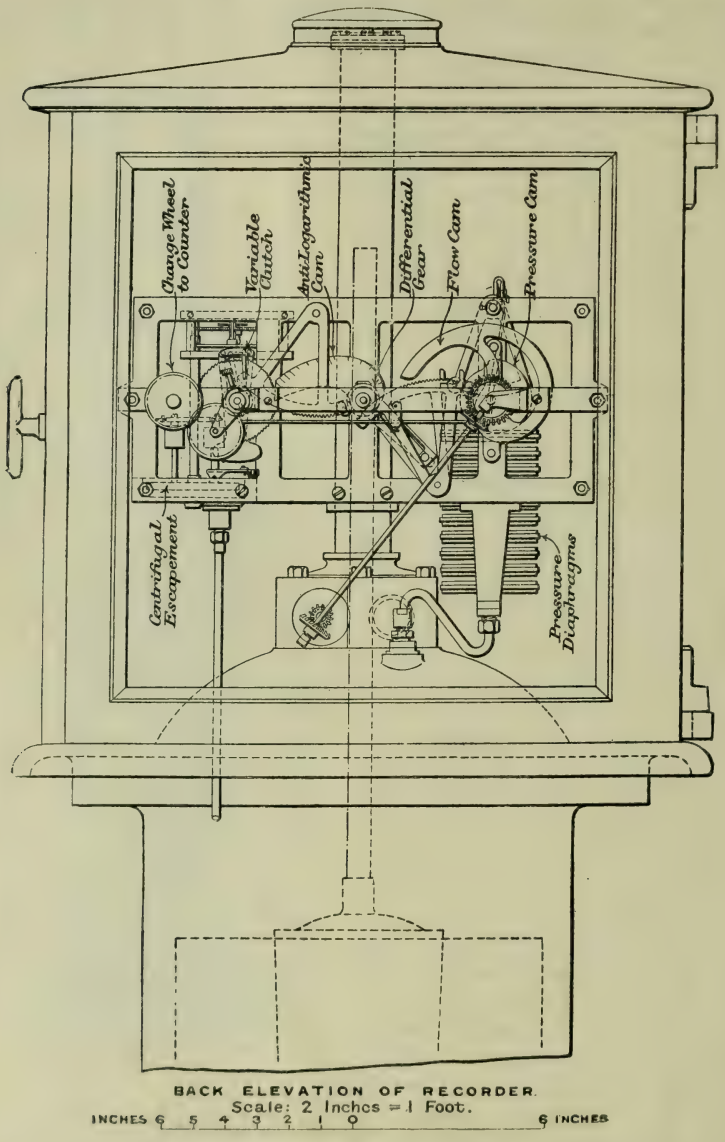


Fig. 9.—The Mechanism of the Victoria Falls and Transvaal Power Company's Meters.

is measured in tons (of possibly unknown calorific value per pound), the steam produced is measured in pounds per hour (with possibly the pressure of delivery not stated), and the air used (again with possibly the pressure of delivery not stated) is measured in cubic feet of "free air."

APPENDIX I.—Venturi Discharge Equation.

The rate of volume flow through a Venturi tube is given by the equation—

$$Q = BK\left[\frac{(p_1 - p_2)T_1}{\Delta\, p_2}\right]^{\frac{1}{2}},*$$

where p_1 and p_2 are the pressures at the points U and T respectively.

T_1 is the emperature at the point U.

Δ is the specific gravity of the gas relative to air at the same temperature and pressure.

K is a numerical constant the value of which depends on the size and proportions of the Venturi tube, the coefficient of discharge, etc.

B is a factor (usually very nearly unity) which allows for the elasticity of the gas.

In the meter shown in Fig. 6 the "Venturi head" $(p_1—p_2)$ is measured by means of the bell B, and an amount proportional to $(p_1—p_2)$ is added on to the counter reading by means of the cam, feeler, and ratchet-and-pawl device C, F, R, G every time the cam G, which is driven by the wet gas-meter W, makes one revolution.

The speed of rotation of this meter is determined by the amount of gas that escapes to the atmosphere from the small orifice O, across which the pressure difference is maintained constant by means of the regulating-valve RV—that is, it is proportional to—

$$\left[\frac{T_4}{\Delta\, p_2}\right]^{\frac{1}{2}} \frac{T_3}{T_4}\frac{p_4}{p_3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where Δ is the specific gravity of the gas relative to air at the same pressure and temperature.

T_1, T_3, T_4 *and* p_1, p_2, p_3, p_4, p_5 are the absolute pressures and temperatures of the gas at the points shown on the diagram.

If the apparatus is so arranged that T_3 and T_4 are made sensibly equal to T_1 and p_3, and p_4 and p_5 equal to p_1, the above expression will be reduced to—

$$\left[\frac{T_1}{\Delta\, p_2}\right]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

So that the quantity registered in any given time is proportional to

$$\left[(p_1 - p_2)\,\frac{T_1}{\Delta\, p_2}\right]^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

—that is, to the product of the square-root of the Venturi head and the speed of rotation of the wet-meter W.

It will be seen that this quantity is proportional to the rate of volume-flow through the Venturi tube, and that the registration of the meter is thus identical with that of a drum type of station gas-meter.

If it be desired to reduce the meter readings to standard cubic feet of dry gas, corrections must be made, by means of tabular numbers, for variations in the barometric pressure, in the atmospheric temperature, and in the tension of acqueous vapour, as is the case with the drum type of station meter—that is, the meter readings must be multiplied by—

$$\frac{p_1 - p'_1}{p_1}\,\frac{p_1}{T_1}\,\frac{T_0}{p_0},$$

where p_1 is the pressure of water-vapour at temperature T, and p_0 and T_0 are the standard (absolute) pressure and temperature.

In the case of the simpler meter shown in Fig. 4, the corrections for variations in the specific gravity, temperature, pressure, and water-vapour content of the gas are made by multiplying the meter readings by tabular numbers calculated from the formula—

$$\text{Corrective factor} = \frac{(p_1 - p_1')}{p_1}\left[\frac{W_0}{W_s}\,\frac{p_1}{T_1}\,\frac{T_0}{p_0}\right]^{\frac{1}{2}},$$

where W_0 = weight of 1 cubic foot of dry gas at p_1 and T_1, and

W_s = ,, ,, ,, ,, gas containing water-vapour at p_1 and T_1.

* See also "The Commercial Metering of Air, Gas, and Steam," by J. L. Hodgson, *Minutes Procs. Inst. C. E.*, 1916-1917, vol. cciv., pages 148-155 and 164-165.

APPENDIX II.—Comparison between a Drum Type of Station Meter and a Venturi Station Meter.

Date.	Amount added, in thousands of cubic feet.		Percentage difference.
	Drum type of station meter.	Venturi station meter.	
September.			
8 to 10	1,267	1,272	+0·5
10 ,, 12	405	411	+1·5
12 ,, 14	1,384	1,402	+1·3
14 ,, 16	1,299	1,313	+1·1
16 ,, 18	1,321	1,331	+0·8
18 ,, 20	1,350	1,358	+0·6
20 ,, 22	1,382	1,383	+0·1
22 ,, 24	1,486	1,501	+1·0
24 ,, 26	1,049	1,062	+1·3
26 ,, 28	1,612	1,608	−0·3
28 ,, 30	1,753	1,755	+0·1
30 ,, 2 Oct.	1,692	1,694	+0·1
October.			
2 to 4	1,311	1,313	+0·2
4 ,, 6	1,559	1,561	+0·1
6 ,, 8	1,564	1,575	+0·6

The President (Lt.-Col. Harry Rhodes): The members of the Institute are much indebted to Mr. Hodgson for the able and interesting way in which he has dealt with the subject of the metering of gas. Would Mr. Hodgson say what is the smallest size of meter that can be adopted? The point that chiefly concerns us as mining engineers is the measurement of compressed air. We do not have to buy it, as is the case on the Rand, but we all have to use it, and if we can have a simple instrument which will tell us how much air any individual engine is using, it will be very helpful.

Mr. J. H. W. Laverick (Tinsley Park): I understand that the meter described is used for the measurement of town gas, but will it measure unpurified coke-oven gas?

Mr. J. L. Hodgson (Luton): A meter of this type has just been erected at Orgreave Colliery for measuring coke-oven gas. It is only being put into operation to-day, so that I am unable to state how it will work, but there is every prospect of its being successful. In this case we are not measuring totally unpurified gas; the gas goes through the tar-extractors, coolers, and scrubbers, and is, therefore, fairly clean by the time it is measured. But it does not pass through oxide beds, which operation is carried out at the gas-works. The meter is placed on the main as it leaves the works at Orgreave.

Mr. Laverick: Will the instrument measure blast-furnace gas?

Mr. Hodgson: Blast-furnace gas usually contains an enormous amount of dust, and unless the mains can be kept clean I am afraid that it is impossible to measure it continuously. If the gas were purified, there would then be no difficulty. We have measured blast-furnace gas in various cases for a few hours at a time, but the pressure-pipes and the main became filled with dust. It was, therefore, necessary to take the measurement as quickly as possible, and to blow through the pressure-pipes before taking each reading. While it is possible to obtain a

measurement that is accurate within perhaps 5 to 10 per cent. under such conditions, it is not practicable as yet to measure uncleaned blast-furnace gas continuously. In the case of clean coke-oven gas, however, there is very little difficulty. Such difficulties as exist are due to corrosion. I have shown on the screen a slide of a Venturi tube which is being used for measuring clean blast-furnace gas. That tube is very big, and in this case a small amount of deposit does not cause any large amount of error.

With regard to the President's question, meters can be made for measuring any quantity of compressed air down to one with a $\frac{1}{2}$-inch pipe. In the paper I read at Doncaster in January,* I described a compact little meter, in which a hinged gate is moved out of the way by the air. This meter is made in a $1\frac{1}{2}$-inch size, and is then capable of measuring 300 cubic feet of free air per minute; the $2\frac{1}{2}$-inch size is capable of measuring about 1,100 cubic feet per minute. The larger size is designed to take an ordinary coal-cutter, and the smaller one to take an ordinary rock-drill or pneumatic tool of that kind. This meter is portable, and is illustrated in Figs. 12, 13, and 14 of my earlier paper (Vol. LX., pages 279-280). I believe that only ninety-six of these meters were sold on the Rand, but after they had been at work for two or three years, it was estimated that the firms using them were saving £130,000 worth of compressed air per year. This example shows the enormous economies that are possible by careful metering.

Mr. D. H. C. Briggs (Whitwood Collieries): Does Mr. Hodgson think there is any great advantage in noting the pressures and temperatures of the air when measuring with the small gate-meter? My company has one of those meters, with which we test our coal-cutters. We do not use pressure-gauges and thermometers to take the pressure and temperature of the air, and I should like to know whether Mr. Hodgson thinks there is likely to be any great source of error through not doing so, or whether, without the use of gauges and thermometers, the results are accurate enough for practical purposes.

Mr. Hodgson: The error is about 1 per cent. for every 10° Fahr., and about 1 per cent. for every $1\frac{1}{2}$ pounds of air at a pressure of 60 pounds. If there is a difference of 2 pounds between the actual pressure and what was assumed to be the mean pressure for which the meter was regulated, the error would be 1 per cent. A table of corrective factors is supplied with each meter, and by reference to this the user can see exactly what error exists at any particular pressure or temperature. Probably, however, when working under fairly uniform conditions, and if all the drills are tested under about the same pressure and temperature, comparative figures will be got that are quite good enough without having to bother to make these additional corrections.

Mr. A. C. F. Assinder (New Monckton Collieries): Is it practicable to put a Venturi tube into any pipe selected, and to carry the meter to, say, half-a-dozen of the tubes?

Mr. Hodgson: In measuring gas we hae not done this, although it would be perfectly possible to do as Mr. Assinder suggests. When steam is being measured, it is our usual practice to do so. Orifices are put in all over the works, with perhaps one meter working on ten different

* *Trans. Inst. M. E.*, 1920-1921, vol. lx., page 271.

orifices. All the meters are calibrated to work at a given maximum head, so that it is possible to change the recorder over to any orifice.

The further discussion of the paper was adjourned.

DISCUSSION OF MR. STANLEY NETTLETON'S PAPER ON "THE FRICTION COEFFICIENT OF MINERALS."*

Mr. Stanley Nettleton (London): Prof. Granville Poole raised some questions at the last meeting, but as he is not present to-day I think it advisable to leave these points over for a written reply, especially as they are matters more to be discussed at the desk, with curves in front of one, than in open meeting.

I have brought with me a few specimens of material, taken from a nut-belt at a colliery, showing the extreme difference in the physical characteristics of dirt picked out from coal. I would also point out that in the separation of minerals it is not only the coefficient of friction that has to be considered, but the form of the mineral also.

Mr. Nettleton subsequently wrote: With further reference to Prof. Poole's questions, I do not think that there is sufficient difference between the friction coefficients of the Beeston or Silkstone coal of Yorkshire and the black shales which often lie immediately above these seams to afford, by frictional means alone, a method of separation on a commercial basis.

In mechanical coal-cleaning another factor must be taken into account: shales have usually a tendency to break into fragments, of which the length, breadth, and thickness are disproportionate to each other. Pieces of bituminous coal are generally of more or less cubical shape. By due recognition of these features, it may be possible to design a machine which will remove efficiently from coal undesirable shales. The presence of black shale in coal is, however, not so objectionable as sandstone or fireclay. In a house-nut it does not attract attention so much as lighter coloured impurities, and in a steam-coal it usually burns to a white floury ash, and is more or less combustible.

The shale from the roof of the Beeston Seam mentioned by Prof. Poole often contains over 15 per cent. of volatile and carbonaceous matter. Analyses of the light-coloured materials found in the vicinity of the seam show that most of these are quite incombustible. Their composition is very variable, as may be seen from the following analyses of dirt from the Beeston Bed at Old Roundwood Collieries, near Wakefield:—

	Underclay.	Clod above coal.	Stone occurring in irregular patches above the seam.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	43·77	61·66	86·46
Alumina (Al_2O_3) ...	45·84	31·47	3·33
Ferric oxide (Fe_2O_3) ...	3·38	1·46	3·34
Lime (CaO)	2·84	2·59	5·19
Magnesia (MgO) ...	2·37	1·55	1·36
Potash (K_2O)	1·12	0·98	trace.
Soda (Na_2O)	0·45	0·31	trace.
Totals	99·77	100·02	99·68

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., pages 69 and 148.

The removal from coal of material consisting almost entirely of alumina, silica, iron, and alkaline salts, which at high temperatures fuse into a sticky mass, is obviously more important than the elimination of dark shales. A dry separating-machine in which the principle of operation depends chiefly on the friction coefficients of material treated may be expected to show greater efficiency in removing from coal associates high in ash content than in dealing with impurities of which the physical and chemical characters more nearly approach that of coal.

The discussion on the paper was closed.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM DECEMBER 4TH TO DECEMBER 31ST, 1921, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
	Dec.														
Sun. ..	4	0	15′0	15′5	15′5	14′5	14′5	16′5	17′0	16′0	15′5	15′0	13′5	14′0	15′0
Mon. ..	5	0	14·5	15·0	15·5	15·0	14·5	15·0	16·5	15·5	15·5	14·5	14·0	13·5	15·0
Tues. ..	6	0	14·5	15·5	15·0	14·5	14·5	15·5	16·5	16·0	15·5	15·0	14·5	14·0	15·0
Wed. ..	7	0	14·5	15·0	15·0	14·5	14·0	15·0	16·5	16·0	15·0	14·5	14·0	14·5	15·0
Thur. ..	8	0	15·0	15·5	15·5	14·0	15·0	16·5	18·0	17·5	15·5	14·5	13·5	14·0	15·5
Fri. ..	9	0	15·0	15·5	15·0	15·0	15·0	16·0	16·5	16·5	15·5	15·0	14·5	13·5	15·5
Sat. ..	10	1	11·0	12·0	14·5	14·0	14·5	16·0	16·5	15·5	14·0	14·5	13·5	12·5	14·0
Sun. ..	11	1	14·5	15 0	15·0	14·5	14·5	16 5	17 0	16·0	16·0	14·0	15·5	13·5	15·0
Mon. ..	12	1	13·5	15·0	14·0	16·5	16 0	17 0	18·5	15·5	14·0	9·5	12·5	13·0	14·5
Tues. ..	13	2	15 5	16·5	16·0	15·0	15 0	16·5	16·5*	14·5*	9·0*	11·0*	8·5*	9·5	13·5
Wed. ..	14	1	14·5	15·5	16·0	15·5	15·0	16·0	16·5	15·5	14·5	13·0	12·5	12·5	14·5
Thur. ..	15	1	15·0	15·5	15·0	14·5	13·5	15·0	16·0	16·0	14·5	13·5	13·0	12·0	14·5
Fri. ..	16	2	14·5	14 0	16·0	15·0	16·0	16·5	18·5	14·0*	16·0*	10·5*	12·0	11·5	14·5
Sat. ..	17	1	13·5	15·0	17·5	17·0	15·5	17·0	18·0	16·5	12·5	9·5	13·0	12·0	14·5
Sun. ..	18	0	11·5	14·5	15·0	15·0	14·0	15·0	16·5	15·5	15·0	14·0	13·5	13·5	14·5
Mon. ..	19	0	14·0	15·0	14·5	14·0	13·0	15·0	16·5	15·0	14·5	13·5	13·0	13·0	14·5
Tues. ..	20	0	13·5	14·0	14·5	13·5	13·5	14·5	15·5	14·5	14·0	13·5	13·5	13·5	14·0
Wed. ..	21	0	14·0	14·5	14·5	14·0	13·5	15.0	16·5	15·5	14·5	14·0	14·0	14·0	14·5
Thur. ..	22	1	13·5	13·5	14 0	14·0	14·0	16·0	17·0	16·5	16·0	14·5	10·5	9·5	14·0
Fri. ..	23	2	8·0	13·5*	12·0	13·5	13·5	15·0	17·0	15·5	14·5	14·5	13·0	10·5	13·5
Sat. ..	24	1	12·5	11·0	11·5	13·5	14·0	15·0	16·0	16·5	16·0	13·5	11·5	11·5	13·5
Sun. ..	25	0	13·0	14·5	14·0	14·0	14·0	15·5	16·5	15·5	14·5	14·5	13·5	13·5	14·5
Mon. ..	26	1	15 0	14·5	14·0	14·0	14·5	17 0	18·5	18·5	18·5	15·0	12·5	7·5	15·0
Tues. ..	27	1	13·0	14·5	14·0	13·5	13·5	15·5	17·5	17·0	17·0	14·5	13·0	12·5	14·5
Wed. ..	28	2	14·5	15·5	18·5	15 0	12·5	17·0	20 0	19·5*	14·5*	9·5*	10·0*	6·5*	14·5
Thur. ..	29	2	11·0*	15·5*	14·0	14.5	15·5	15·0	15·0	14·0	11·0	11.0	10·5	11·0	13·0
Fri. ..	30	1	15 0	14·5	15·0	14·0	13·0	14·5	15·5	15·0	13·5	12.0	10 0	11·0	13·5
Sat. ..	31	0	13·0	15·0	14·5	13·0	13 0	14·0	14·5	14·5	13·5	12.5	12·5	13·0	13·5

Diurnal Inequality (*i.e., departure from mean value for day*).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
December, 1920	−1′0	−0′4	0′0	−0′1	0′0	0′0	0′0	0′0	+0′4	+1′3	+2′0	+2′4
November, 1921	−1·0	−0·4	−0 3	−0·3	−0·1	−0·1	−0·3	−1·2	−1·3	−0·2	+1·4	+2·7
November, 1920	−2·0	−0·6	−0·9	−0·7	−0·8	−0·7	−0·6	−0·7	−0·3	+1·2	+2·4	+3·3

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
December, 1920	+2′3	+1′8	+1′2	+0′8	+0′3	−0′2	−1′0	−1′2	−1′7	−2′7	−2′2	−1′8
November, 1921	+3·3	+2·8	+1·9	+1·1	+0·5	−0·2	−1·3	−1·1	−1·6	−1·7	−1·7	−1·1
November, 1920	+3·7	+2·9	+2·4	+1·8	+1·0	+0·1	−1·1	−1·8	−2·1	−2·5	−2·1	−2·0

* Large disturbances during this interval.

Mean Value for Month.

December, 1920.	November, 1921.	November, 1920.
14° 26′·3.	14° 15′·0.	14° 27′·2.

THE MIDLAND COUNTIES INSTITUTION OF ENGINEERS.

GENERAL MEETING,

Held at the University College, Nottingham, December 10th, 1921.

Major T. P. BARBER, D.S.O., President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen were duly elected :—

Members—

Mr. James Gordon Mein, Manager, South Normanton Colliery, Alfreton.

Mr. Samuel Leslie Potter, Manager, Mining Prospecting Syndicate (Malay States), Fairlawn, Market Harborough.

Mr. Arthur William Warburton, Colliery Manager, 82, London Road, Coalville, Leicester.

Student—

Mr. George East Winfield, Mining Student, 47, Bridge Road, Coalville, Leicester.

Mr. J. W. Whittaker read a description and gave a demonstration of the Davis-Derby Autokap chamber for the production of various gas-caps on safety-lamp flames.

NOTES ON COAL-WASHING BY THE "RHÉOLAVEUR" PROCESS.

By A. FRANCE-FOCQUET, Engineer A.I.Lg., Engineer-in-Chief, Société Anonyme des Charbonnages de La Haye, Liége, A.I.M. ; and H. EUSTACE MITTON, M.Inst.C.E.

I.—Washing of "Fines."

The selling of coal by its calorific value is one of the most important questions before the coal industry to-day, and the object of this paper is to raise a discussion on the simplest and most economical lines on which coal can be cleaned so as to place it on the market in its best form.

The principal points to consider are the following :—(1) The separation of coal from the dirt, so as to leave a minimum quantity of dirt in the washed coal, and, *vice-versa*, the least amount of coal in the dirt.

(2) The first cost of the plant and the cost of labour and upkeep in running the plant, so that the total cost per ton does not make the price for the washed coal prohibitive in competing on the market.

The washing of coal can be classed under two heads, namely : (1) washing of the nuts and peas, and (2) washing of the fines.

The Rhéolaveur process has been recently adopted with great success on the Continent, and is gradually coming into prominence in this

country. This process is the subject of this paper, and the various features and details of working of the plant are fully described.

In order to obtain an efficient screening in as simple a manner as possible, it is necessary to limit the size of fines to $\frac{1}{4}$ inch; when coal is not dry, it is essential to screen it to $\frac{5}{16}$ inch, and sometimes, to obtain a perfect classification in those conditions, it is advisable to make a wet screening.

Acknowledging that the washing of fine particles is, by all systems, inefficient, practical men and constructors of washeries have had to resort to the extraction of the dust and mud from the coal.

The apparatus for extracting the dust from fines, which consists of vibrating sieves or pneumatic appliances, is thoroughly efficient when the coal is dry; but in all cases, and especially when the size of the dust to be extracted is less than $\frac{1}{50}$ inch, there remains a considerable proportion of dust, the treatment of which in washeries has always been the cause of many difficulties.

It is necessary here to refer to what has been written on the phenomena of equivalence, in pursuance of which some competent men have advanced the opinion that washing of coal under $\frac{1}{10}$ inch is almost an impossibility.

The jig system, for example, does not give ideal results, on account of the great fault of this process, namely, the suction caused by the pulsating motion.

On the other hand, all the tests in the apparatus which obtain the separation by ascending currents only (for example, the Draper apparatus) generally achieve little success when it is necessary to treat coal between 0 and $\frac{5}{16}$ inch in one operation. It was therefore necessary to make research in other directions.

One phenomenon which has not sufficiently attracted attention is the different manner in which shale of flattened shape behaves from grains of coal (of more or less cubical shape) when they are submitted to the action of a horizontal current. Whilst the grain of coal presents a relatively large section to the water-stream which bears it along with remarkable facility, the grain of shale, being flat, presents a smaller section to the stream, and is therefore carried along at a greatly reduced velocity. On the other hand, when a grain of coal and a grain of shale are dropped into a test-tube full of water, both having the same size of classification, but not of volume, it is found that the velocity of sinking varies very little, both grains reaching the bottom of the tube almost simultaneously. If these two motions be combined, namely, a horizontal current and a vertical fall, the piece of shale will reach the bottom of the trough before the grain of coal.

It will be readily appreciated that it is possible under these conditions to obtain a deposit of heavy material after it has passed through a sufficiently long portion of trough, this length depending on the velocity of the horizontal current and the sizes of the particles. The heaviest and largest particles are the first to be deposited, followed by other grains, in order of weight and size, in the direction of the current. The operation will, in all likelihood, proceed as follows:—

The deposit of shale will form a downstream slope; when this inclined surface has reached a certain height, the shale which falls on to it will be carried very slowly along under the action of the current by reason of its shape and friction with the afore-mentioned deposit of shale. Consequently, a very slow movement will be obtained of the heaviest shale over the above bed, which movement can be regulated by various methods.

By placing a slot at a given point in the channel, shale will fall through, causing a depression in the bed. In order to ensure that the lighter particles are not passed through this slot, it is necessary to prevent the water in the channel from plunging through it. The means employed, therefore, is an upward current of water through the slot. It can be readily appreciated that if the bed of shale is thick enough, and the size of the slot adequate, it is sufficient for a comparatively weak upward current to ensure that only pure shale shall pass through the slot.

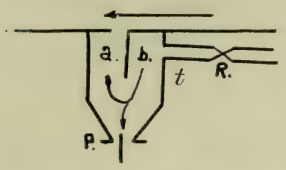


Fig. 1.—Diagram of Rhéolaveur Apparatus.

The apparatus employed to realize this function is the "Rhéolaveur," which is composed of a cast-iron box of pyramidical shape, the base of which is fixed into the trough, whilst the top is provided with an orifice for the evacuation of separated product. The base of this box is divided into two parts: one (*a*) has a slot, and the other (*b*) is the water-inlet chamber, being fed by means of the pipe *t* (Fig. 1). This water, which is under pressure, produces an upward current through the slot and a downward current through the orifice at the bottom.

The flow of water is regulated by the cock *R*, the evacuation of the shale being regulated by a plate *P*, provided with various sized conical orifices, the object of which is to reduce the water-consumption in the Rhéolaveurs to a minimum; consequently, with a given number of

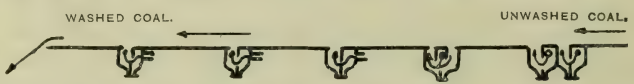


Fig. 2.—Arrangement of Rhéolaveurs in Series.

apparatus placed in series (Fig. 2), employing upward currents of water of practically no velocity, it is possible to extract a large quantity of the shale, which is deposited more or less through the whole length of the trough.

It must be pointed out that the upward currents have a direct effect upon the classification of the material carried along in the trough and not falling through the slot. There is no doubt that these currents tend to lift up the lighter particles above the heavier ones, preparing in this way the layer of shale which is extracted by the following apparatus.

It is interesting to note that each apparatus takes out shale, the particles of which diminish in size at each succeeding aparatus, realizing thereby a progressive separation of heavy shale, the volume of which becomes more and more reduced, and facilitating the regulation of the apparatus.

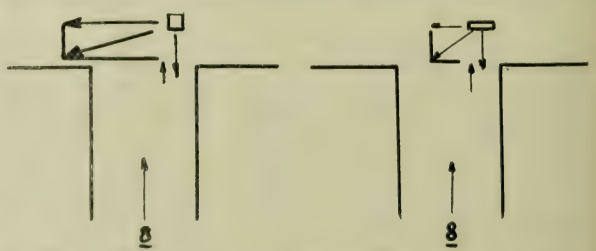


Fig. 3. Combination of Horizontal Movement and Sinking of Coal and Shale.

If the layer of shale which is moved by the action of the horizontal current in the trough is too thin, it may happen that some large grains of coal will fall through the slot. To prevent this, it is necessary to increase the velocity of the upward current. It is

remarkable that the velocity of the particles of varying specific gravity (carried along by the water in the trough), by reason of their various shapes, is of such value that it allows of upward currents of low velocity to obtain an ideal classification (Fig. 3).

Consider two particles of different specific gravities (carried along by a horizontal current) in the same horizontal layer and standing over the slot. Put them under the action of upward currents of water through the slot, assuming that currents to be equal in each case. This assumption can be allowed, as these particles have passed through the same screen, and as each presents to the upward current its largest section. As this shale offers to the horizontal current its smallest section, whilst the grain of coal independant of its position offers a section of almost uniform size, consequently larger than that of the grain of the shale, it follows, therefore, that the grain of coal rolls over the bed formed by the heavy particles, whilst the grain of shale slides and is retarded by the friction caused by contact with the deposited heavy particles. Consequently, the grain of coal will have a greater velocity than that of the

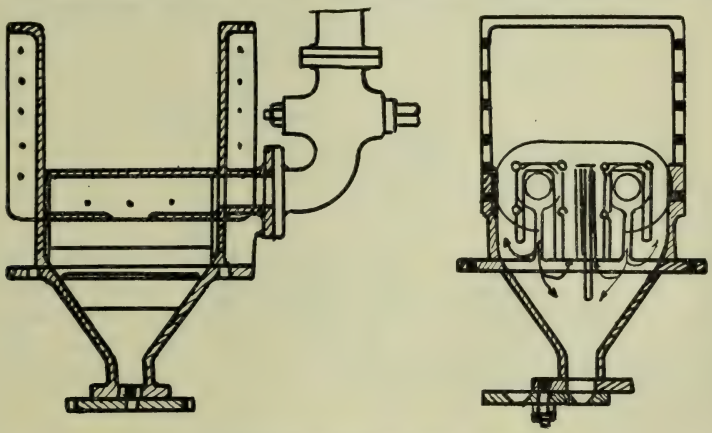


Fig. 4.—Detail of Rhéolaveur Apparatus.

grain of shale. On combining these velocities, it is found that the coal is carried over the slot, whilst the shale, despite the upward current, plunges through the slot into the Rhéolaveur apparatus.

As at the point where the upward current acts—that is to say, just above the slot—the downward velocity of the particles of coal is almost negligible, the upward current, in order to counteract this motion, need only be of weak character.

At the end of the trough the classification is more complicated. As the impurities to extract at this stage are very thin pieces of shale or very small dirty particles, it is necessary to reduce considerably the velocity of the current to the trough, and to induce the separation by some suitable means. The extracts of the bottom trough can be obtained by employing special Rhéolaveurs (Fig. 4) which evacuate the products without causing a great depression in the trough.

In order to obtain at the end of the trough coal cleansed from all heavy particles of shale, and as it is preferable to cut short this gradual classification (which necessitates an infinite number of apparatus), the last apparatus in the trough are regulated to extract a product in which is contained a small percentage of coal, thereby ensuring that pure coal only shall pass over the apparatus to the end of the trough, the evacuated product being submitted to a second treatment.

By using a trough, as described above, a clean coal is obtained, but at the same time it is necessary to obtain also pure shale. Those who have had experience in washeries know that the feed of the products to be treated is far from being constant in quantity and quality. It is, therefore, impossible with such an installation as already described to obtain a perfect adjustment of the apparatus to realize an absolutely complete separation of pure shale from coal, and this is so with all types of washeries, especially with regard to the last apparatus, which is always regulated to extract a mixed product. It is obvious, therefore, that these mixed products should be rewashed, and this operation was first carried out by the jig system, the results of which were deplorable. Experiments were afterwards made by rewashing in another trough fitted with Rhéolaveurs placed underneath the first trough (Fig. 5), this arrangement being called "battery in cascade."

By the above means, the last apparatus of the first trough evacuate their middle product directly into the second trough. This stream of product, falling from the upper to the lower trough, produces in the lower one a definite layer of material of intermediate specific gravity, forming an impassable barrier between the coal and shale, thus resulting in a complete separation. Similarly in the second trough shale can be evacuated by the Rhéolaveurs and clean coal passed over the end.

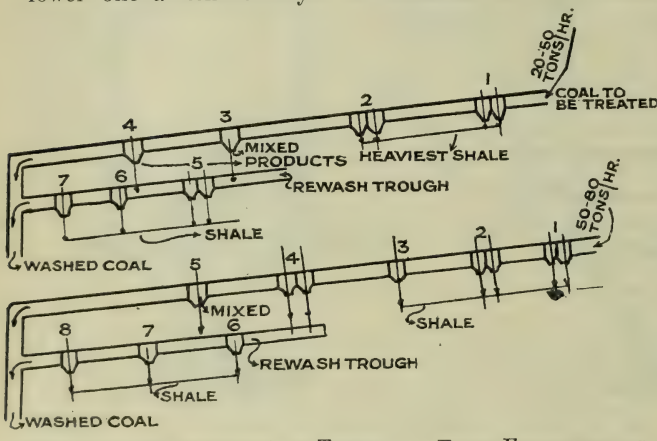


FIG. 5.—ARRANGEMENT OF TROUGH IN FIRST EXPERIMENTAL RE-WASHING.

In order to make a further classification, a third trough is placed beneath the second (Fig. 6). The Rhéolaveur apparatus in this third trough are so arranged as to evacuate pure shale. To ensure this, it is necessary to allow a portion of the shale to go forward mixed with the coal, this mixed product being taken by an elevator to the head of the first trough in view of further treatment.

This rewashing by means of an elevator is an outstanding feature of the Rhéolaveur system of washing, as it also serves as an infallible rectifier of all irregularities caused by variation in the quality of the product treated.

Mr. Lambert Lecocq points out the importance of this rewashing, as follows:—

It is known perfectly well that rewashing constitutes a true regulator of the plant, and it completely annuls the effects produced by the variations of qualities or of degrees of impurity of the raw coal, and it is, therefore, necessary to proportion the capacity of the regulating elevator according to the importance of the maxima of these two agents.

Suppose, for example, that a plant has been designed to treat normally T tons of coal. If there is not a regulating distributor of raw coal, this supply may be brought during a certain time to a maximum

value T. Suppose also that the quantity of the waste evacuated normally is q per ton of raw coal. Now regulate the Rhéolaveurs for final shale so that they evacuate regularly this quantity q of shale.

As coal varies in composition—that is to say, contains in certain cases a maximum quantity q of shale per ton—it is necessary to provide for an overweight of shale which is not taken out by the finishing

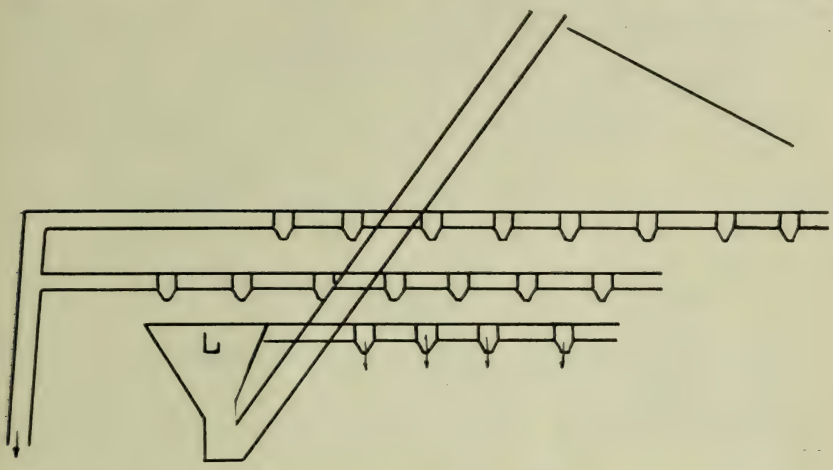


FIG. 6.—EXISTING ARRANGEMENT OF TROUGHS AND RE-WASHING BY ELEVATOR.

Rhéolaveurs, and which is equal to $Q = T'q' - Tq$. This overweight must, therefore, be taken away by the rewashing elevator.

Generally, it is known that the supply of the rewashing elevator is superior to this quantity Q. This is owing to the fact that incorporated in this product is a rather important quantity of $Q2$ of middlings, which it is possible to circulate in the plant throughout an

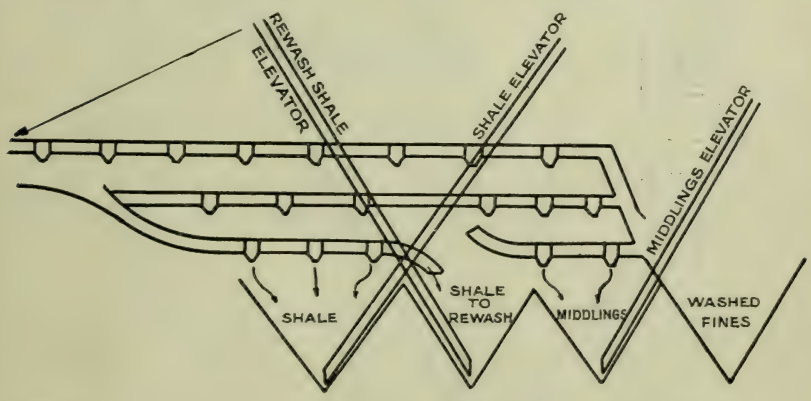


FIG. 7.—ARRANGEMENT OF RHÉOLAVEURS TO PRODUCE A MIXED PRODUCT.

indeterminable length of time. This quantity of middle product has an extremely advantageous classifying power, by forming in the bottom bed a layer of an increasing thickness that lies between the layers of shale and coal. This layer separates perfectly, by means of a continuous partition, the particles of coal from the particles of shale.

It is important that the particles of coal shall not roll on those of shale, therefore necessitating the maintenance of the afore-mentioned

layer of middle product. This effect of this classifying agent, added to that of regulating, justifies the use of an elevator, the capacity of which must be adequate.

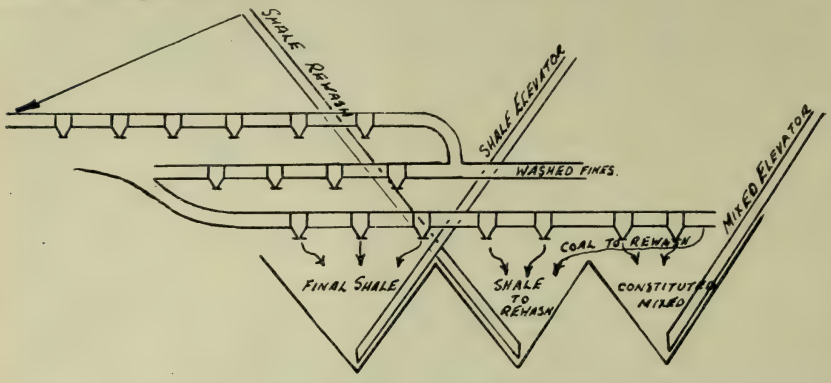


Fig. 8.—Alternative Arrangement of Rhéolaveurs to produce a Mixed Product.

When it is required to produce a class of middle products, these can be obtained by two different ways, namely :—

(1) By treating in a third trough the product evacuated by the last apparatus of the second trough; the Rhéolaveurs of this third trough

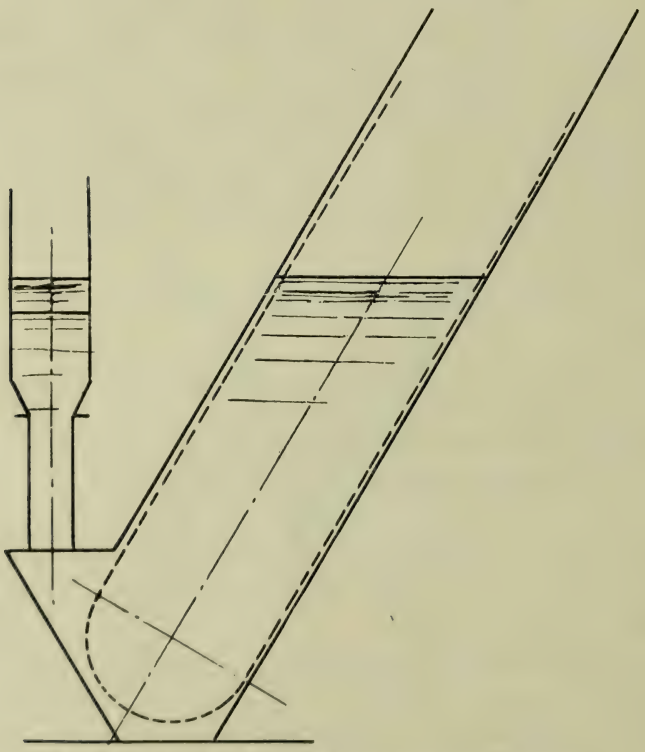


Fig. 9.—Section of Sealed Apparatus and Elevator.

evacuate a product of intermediate specific gravity (being a combination of coal and shale), known as middle product, allowing clean coal to pass over the end of the trough, where it joins washed coal from two upper troughs (Fig. 7).

(2) By treating the products of the third trough by four supplementary apparatus, Nos. 1 and 2 of which evacuate shale, to be rewashed in the plant, whilst the other two give nearly pure middle products. The product over the end of the trough is brought into a hopper to be rewashed (Fig. 8).

II.—Washing of Large Sizes.

The washing of large coal from $\frac{7}{16}$ inch to $3\frac{1}{8}$ inches is based on the same principle as the washing of fines.

Here, however, a single trough is used, fitted with only two Rhéolaveur apparatus. These are necessarily larger than those for dealing with the fines, on account of the greater volume to be evacuated. These apparatus are each fitted to a sealed elevator having perforated buckets, which allow of the discharge of material without loss of water (Fig. 9).

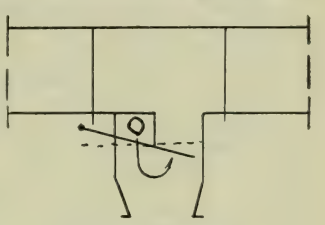


Fig. 10.—Section of Rhéolaveur, showing Action of Flap-valve.

In the treatment of fines an ascending current of extremely low velocity is sufficient to allow the particles of coal to pass over the slot, which can be relatively narrow, due to the small diameter of the shale which has to fall through it; but with apparatus of the same type used for large coal, the slot would have to be much wider, and on this account it would require ascending currents of considerable velocity to prevent pieces of coal from falling down through the slots, necessitating an enormous circulation of water, which would greatly prejudice the process of washing even in the case of an apparatus of perfect efficiency.

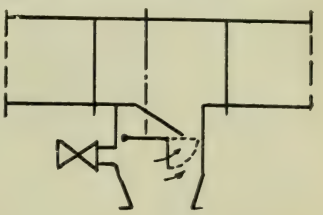


Fig. 11.—Section of First Sealed Rhéolaveur.

As it is essential to maintain the slot full of shale, it was decided to try to obtain this result by mechanical means; hence the idea of a flap-valve placed at the bottom of the slot (Fig. 10).

Under the action of the weight of shale, and regulated by a counter-weight, this valve had to open automatically more or less to allow a certain quantity of shale to fall down continually. This continual automatic evacuation being almost impracticable, it was substituted by a mechanical intermittent evacuation, producing in the trough over the slot a state of continuity of the bed of shale, thus allowing no coal to fall down with the shale through the slots. The slot, however, was replaced by a more spacious chamber.

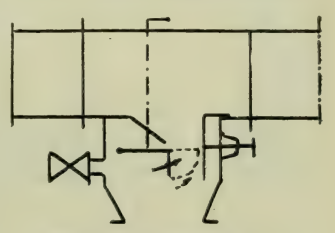


Fig. 12.—Section of Improved Sealed Rhéolaveur.

If this chamber be of sufficient capacity, it is found that the flap-valve can evacuate, at each oscillation, a certain quantity of shale, and that this action does not lower the upper surface of the bed of shale. The apparatus shown in Fig. 11 has therefore been evolved.

This oscillating flap-valve, the principle object of which is to regulate the evacuation of shale moving from a more or less inclined position to a horizontal position, produces to a certain degree an effect similar to the plunging in hydraulic jigs, namely, suction. However, the flap-valve

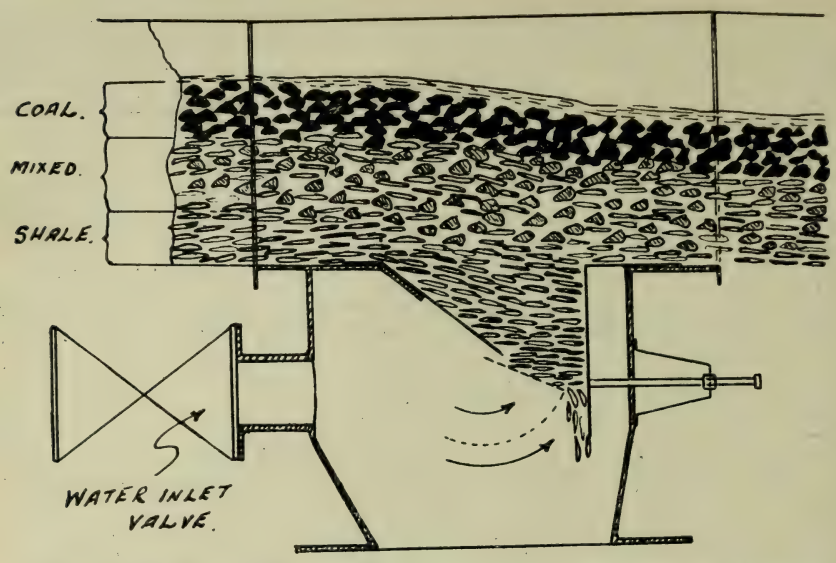


FIG. 13.—SECTION OF SEALED RHÉOLAVEUR, SHOWING SEPARATION OF MATERIAL.

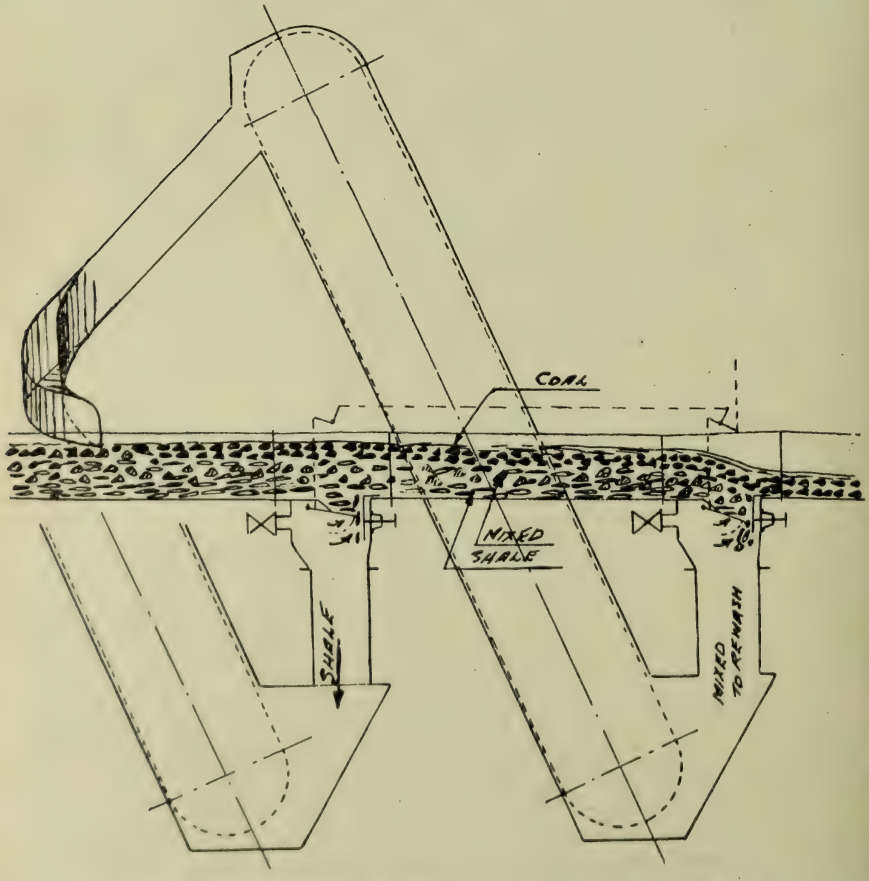


FIG. 14.—ARRANGEMENT OF APPARATUS TO TREAT LARGE SIZES.

has since been perforated, thus allowing a free passage for the upward current of water coming underneath, and thereby eliminating this suction.

It can be readily understood, after what has been said, that the upward current in these Rhéolaveurs can be of extremely low velocity, even when treating sizes up to 3 or 4 inches.

Some detailed improvements have been added to the first design of the sealed Rhéolaveurs fitted with flap-valves. One of these consists of a vertical slide-valve (Fig. 12), which by moving horizontally allows of a modification in the size of the separating-chamber, and also regulates the section of the shale orifice.

An apparatus of extraordinary elasticity has, therefore, been arrived at, permitting of the treatment in the same plant of either a great or a small quantity of material, or of changing with great facility from the treatment of sizes of from $\frac{1}{4}$ inch up to 3 or 4 inches; this can always be done with absolute efficiency and economy.

As in the plants for fines, the evacuation of shale is effected by a first apparatus in such a way that a small quantity under normal conditions passes over the apparatus, so that it is certain to obtain with this apparatus absolutely pure shale. This is shown clearly in Fig. 13. This classification of the products (coal, middle product, and shale) is maintained directly over the apparatus.

As the aim is ideally clean coal, it is necessary to regulate the second apparatus so that it may evacuate rather more than the quantity of shale and middle product available; consequently, it would evacuate also a small proportion of coal. This mixture of material is conveyed by the elevator to the head of the trough for rewashing, allowing clean coal only to pass over the end of the trough, thus realizing by means of two apparatus (Fig. 14) that on the one hand absolutely pure shale and on the other clean coal shall be produced.

III.—Water Supply.

It has been proved that the quantity of circulating water necessary in Rhéolaveur washeries is much less than that required by the "jig" system, as the following examples will show:—

At Fief de Lambrechies Colliery the old water-circulation pump has been maintained, whilst the output of the new washery (Rhéolaveur) has been increased to a considerable degree.

At La Haye Collieries, Liége, Belgium, there are two washeries, each of a capacity of 70 tons per hour, in which the circulating water required is only 77,000 gallons per hour, and the horsepower only 35.

At the Pont-a-Vendin washery, Lens Collieries, the jigging system has been replaced by the Rhéolaveur system and adapted to the existing plant. The capacity of the jigs was 80 tons per hour, whilst the Rhéolaveur system increased this to 115 tons per hour. Further, the installation of the Rhéolaveur allowed of the scrapping of one of the centrifugal pumps necessary in the jig system, which required 100 horsepower to drive.

Moreover, it must be pointed out that the quantity of water supplied by the circulating pump relative to the tonnage to be treated is so much the smaller as the supply of coal in each plant is greater. The contrary happens in all other types of washeries where the washing is not progressively performed as in this process of washing by Rhéolaveurs. For example, a washery of 60 tons, with six plants of

Rhéolaveurs of 10 tons each, would require a circulation of water rather more than that for plunger-jigs of the same capacity. But a washery of 60 tons, with three plants of Rhéolaveurs of 20 tons each, would require a pump the capacity of which would be only three-quarters that of a pump necessary to supply a plant of plunger-jigs treating the same quantity of coal. The supply of the pump for a washery of 120 tons, with three plants of 40 tons each, would be 50 per cent. less, and that for a washery of 200 tons, with four Rhéolaveur plants of 50 tons each, would be nearly 60 per cent. less. With Rhéolaveurs, therefore, there is no difficulty in determining the most advantageous supply from this point of view, even for washeries of small capacity.

In order to give an idea of the efficiency of the washing by Rhéolaveurs, the results obtained by test of various coals at La Haye Colliery are given in the following table :—

Tests made in "Rhéolaveur Washeries" on Various Coals at La Haye Collieries, Liége.

Size.		Percentage of ash.			Percentage of ash required.
		Raw coal.	Washed coal.	Shale.	
Laveu Washery.					
50 *Tons* 0/55, "*Marcinelle Nord Collieries*," *May* 29*th*, 1920.					
Inches.	Millimetres.	Per cent.	Per cent.	Per cent.	
0—$\frac{1}{5}$	0— $\frac{1}{2}$	18·0	15·0	59·0	—
$\frac{1}{5}$— $\frac{1}{3}$	$\frac{1}{2}$— 8	31·0	8·7	80·3	—
$\frac{1}{2}$— $\frac{7}{8}$	8—20	38·5	6·2	80·9	—
$\frac{7}{8}$—2$\frac{1}{2}$	20—60	41·6	5·8	87·7	—
55 *Tons* 0/55, "*Ormonde Collieries*," *February* 13*th*, 1921.					
0— $\frac{1}{3}$	0— 8	13·5	8·0	75·8	—
$\frac{1}{3}$— $\frac{7}{8}$	8—20	26·1	6·1	74·7	—
$\frac{7}{8}$— 1	20—25	37·7	5·0	82·1	—
Tilleur Washery.					
55 *Tons* 0/60, "*Hyon Cyply Collieries*," *June* 12*th*, 1920.					
0— $\frac{2}{5}$	0—10	23·5	7·7	72·8	—
$\frac{2}{5}$— $\frac{7}{8}$	10—20	33·5	3·3	75·0	—
$\frac{7}{8}$—1$\frac{1}{4}$	20—30	32·7	4·0	78·6	—
1$\frac{1}{4}$—2$\frac{1}{2}$	30—60	31·2	2·4	77·3	—
50 *Tons* 0/60, "*Bois-de-Lac Collieries*," *August* 8*th*, 1920.					
0— $\frac{1}{5}$	0— 5	24·2	9·0	67·0	—
$\frac{1}{5}$— $\frac{1}{2}$	5—12	28·0	7·8	75·2	—
$\frac{1}{2}$— $\frac{7}{8}$	12—20	34·5	8·4	77·8	—
$\frac{7}{8}$—1$\frac{1}{4}$	20—30	35·3	4·5	80·3	—
1$\frac{1}{4}$—2$\frac{1}{2}$	30—60	36·5	4·2	82·7	—
60 *Tons* 0/60, "*Maurage Collieries*," *February* 28*th*, 1921.					
0— $\frac{1}{10}$	0— $\frac{1}{2}$	27·5	20·5	61·5	—
$\frac{1}{10}$— $\frac{1}{5}$	$\frac{1}{2}$—2$\frac{1}{2}$		11·5	61·0	12·0
$\frac{1}{10}$— $\frac{1}{5}$	2$\frac{1}{2}$— 5	28·5	9·0	69·5	10·0
$\frac{1}{5}$— $\frac{1}{2}$	5—10		8·2	67·5	—
$\frac{1}{2}$— $\frac{7}{8}$	10—20	28·2	8·0	68·5	7·8
$\frac{7}{8}$—1$\frac{1}{4}$	20—30		4·9	77·0	6·7
1$\frac{1}{4}$	30	—	4·7	84·4	6·7
"*Bolsover Collieries*," *October* 30*th*, 1921.					
0— $\frac{1}{2}$	0—12	24·5	7·5	71·5	—
$\frac{1}{2}$— $\frac{7}{8}$	12—20	22·0	4·8	78·5	—
$\frac{7}{8}$—1$\frac{1}{4}$	20—30	20·0	5·0	78·0	—
1$\frac{1}{4}$—2$\frac{1}{2}$	30—60	29·0	5·5	79·5	—

These tests were performed on 50 to 60 tons of 0—$\frac{3}{8}$-inch coal. The results were for the fines better than those obtained by plunger-jigs. For the large categories, also, the separation was really perfect.

If it be considered that owing to the large capacity of the washery these tests are often of very short duration, this proves what adaption and precision there is in the regulation of the process of washing by Rhéolaveurs. Compare this regulation with that of the plunger-jigs in which whole days and sometimes months are required to obtain a more or less perfect washing, and which moreover requires, from the view of the operator, an experience that very few can acquire.

The choice of a plant, therefore, depends upon the following factors :—

(1) The sum to be spent on the plant.

(2) The capacity of the washery.

(3) The site upon which to erect the plant.

(4) The possibility of dust-extraction from dry coal.

(5) The facility of loading or of storing the washed product.

(6) The degree of purity required for each class of material treated.

Figs. 15 to 21 show the general arrangement of a Rhéolaveur washery to treat 160 tons of 0-2-inch coal per hour, and are self-explanatory.

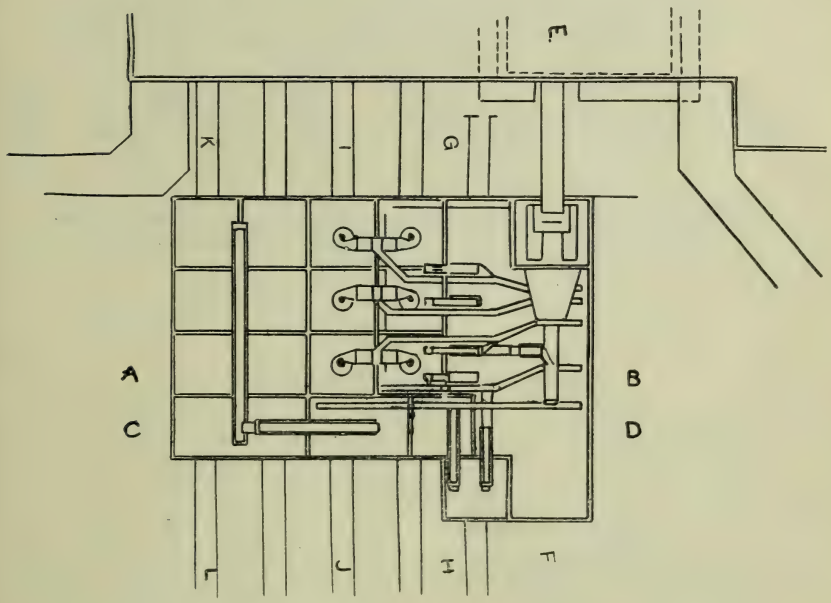


Fig. 15.—Plan of Rhéolaveur Installation.

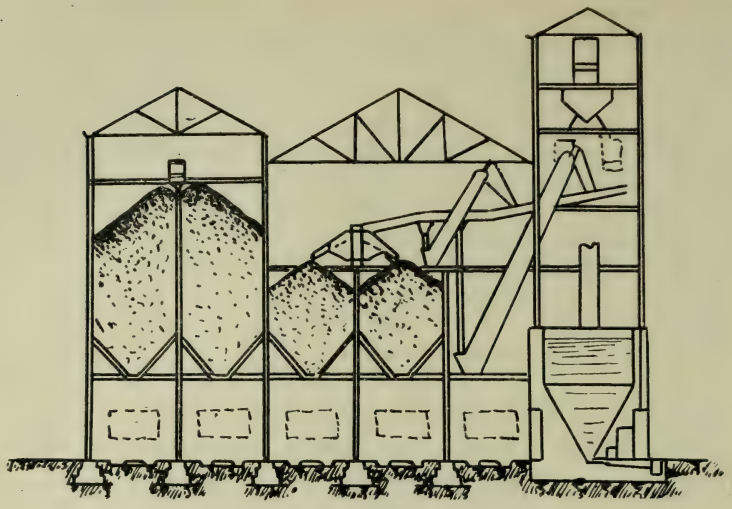


Fig. 16.—Section on Line A–B of Fig. 15.

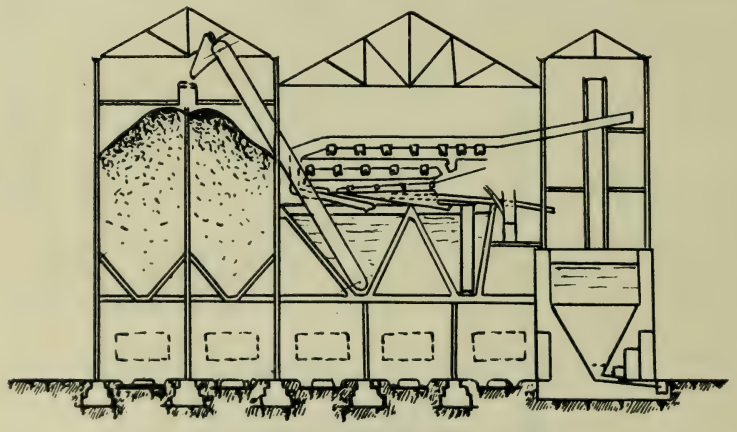


Fig. 17.—Section on Line C–D of Fig. 15.

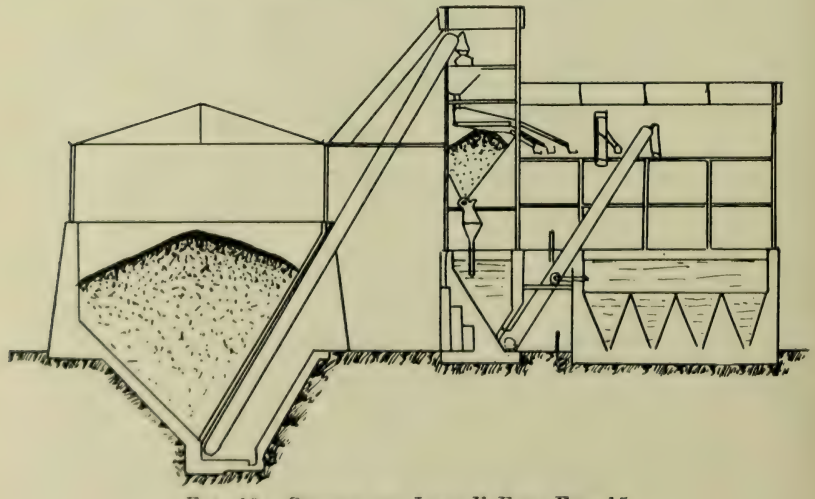


Fig. 18.—Section on Line E–F of Fig. 15.

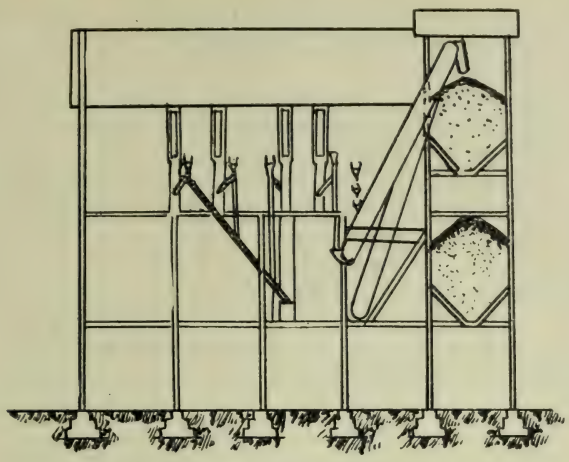


FIG. 19.—SECTION ON LINE G–H OF FIG. 15.

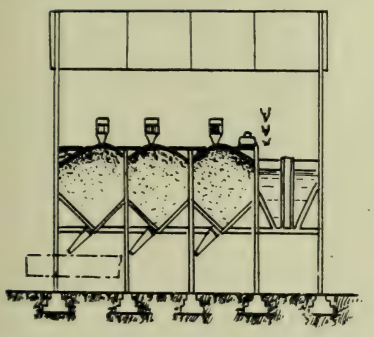


FIG. 20.—SECTION ON LINE I-J OF FIG. 15.

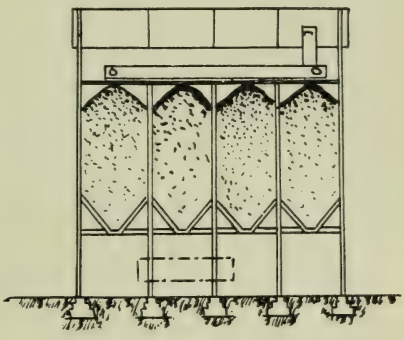


FIG. 21.—SECTION ON LINE K-L OF FIG. 15.

Owing to their ability to produce perfect washing on account of their simplicity, and to the possibility of using inexpensive buildings, the use of Rhéolaveurs solves all the problems of washing coal in such a manner that no other system of washing can compare with this process.

IV.—SLUDGE.

Before concluding, it may be useful to show how sludge behaves in the process of washing by Rhéolaveurs. The treatment of sludge is, of course, an interesting problem, and generally not well known.

In the section on the washing of fines the method of how to treat the finest particles is indicated precisely, namely, by placing the apparatus in series along a trough.

It has been said that it is practically possible to separate the particles of shale of which the diameter is less than $\frac{1}{50}$ inch, but the separation can be done in certain cases to $\frac{1}{100}$ inch.

It may be remembered that, as there is no mechanical washing in the Rhéolaveur process, there is no friction to cause breakage of shale and coal and thus produce fine particles, and consequently sludge, as is the case with jigging.

It can be seen, therefore, that the Rhéolaveur, unlike the jig-system, does not produce sludge, the only sludge that accumulates being that

caused by the dust in the unwashed material. This defect can be remedied when coal is dry by extracting the dust before washing, as already described.

In the case where the raw fines, on account of their degree of humidity, cannot be freed from their dust, it is preferable (whether the 0—$\frac{1}{50}$-inch material is clean or dirty) to submit them to washing. There is thereby a chance of obtaining a certain separation of the finest shale.

If the 0—$\frac{1}{50}$-inch material, after washing, is found to be clean, it is desirable to obtain as large a deposit of this product in the fines hopper as possible (necessitating the provision of a hopper of large size) and to induce the deposit by some special means.

If, on the contrary, the 0—$\frac{1}{50}$-inch material, after washing, is found to be dirty, and has to be entirely or partly eliminated from the washed fines, the washed-fines hopper must be of such a size and disposition that the overflow will carry along with it the proportion of the 0—$\frac{1}{50}$-inch stuff that it is necessary to separate.

This procedure is not, however, always the most advantageous, as it may happen that, by effecting the elimination of these dirty particles in the above manner, a certain quantity of fine particles of coal measuring about $\frac{1}{50}$ inch will also be eliminated. The following method, therefore, has been adopted :—

As the washed fines are shot from the elevator to the storage-bunkers, they pass over a wire gauze having a mesh of $\frac{1}{50}$ inch or less, and a supply of clean water is sprayed over them. This allows of the elimination, according to the amount of rinsing, of a more or less greater proportion of sludge; on the other hand, it reduces to a minimum the loss in sludge by adopting sizes of mesh in relation to the sizes of the dirty particles to be separated.

Whatever be the means adopted to separate the sludge from the washed fines, the former must be collected in order that the water may be clarified and used over again. If this water be not well clarified, the washing-water would be full of sludge, which would be carried along through the plant. Though this is not a very serious defect, its occurrence must be avoided within the bounds of possibility, as the result of this insufficient clarification would cause a greater percentage of ash to be present in the washed fines.

The arrangement adopted to obtain the clarification of the water consists of V-shaped tanks, in which the dirt settles to the bottom, where it is drained off by means of suitable valves, obtaining thereby the evacuation of thick sludge.

It is better to have a continual evacuation of this sludge rather than intermittent draining. It has been proved that the sludge in these tanks rapidly sticks to the walls, reducing thereby the size of the tanks, and consequently their efficiency. By a continuous draining of the tanks, the above-mentioned sticking would be eliminated.

The overflow from all hoppers, conveyors, Rhéolaveur apparatus, etc., runs to these settling-tanks, whilst the clear water on the surface is pumped to a storage-tank, which feeds the troughs and the Rhéolaveur apparatus.

Nothing further need be said on this subject, the desire in question being to give a general idea of what takes place in the simplest Rhéolaveur plants when treating sludge.

Mr. H. Eustace Mitton (Codnor): I may add that the Butterley Company are already erecting a large washer of this type, and it is

expected to be completed early in 1922. We have a small washer of the same kind at work, but I hope that when the oft-deferred visit of the members to the Butterley Company's works takes place, they will be able to witness the washing of coal by the large washer. In the meantime, if any member would like to see the small one, permission would readily be given.

The discussion of the paper was adjourned.

DISCUSSION OF MR. H. EUSTACE MITTON'S PAPER ON "PIT-SHAFTS."*

Mr. H. Eustace Mitton (Codnor): I am sorry I was unable to be present at the last meeting when my paper was read, but I am now glad of the opportunity of replying to the various points raised by those who took part in the discussion.

The President seemed to doubt the possibility of getting an adequate supply of air over an area of 6,000 acres by means of a 15-foot shaft. In reply, I may say that I know of large areas which are being worked at a depth of 500 yards with a 15-foot shaft; and although they may not be so large as in the case referred to, I think they could be safely and satisfactorily worked with that size of shaft. I took out some particulars at our own collieries, and found that at one pit where we work at a depth of 345 yards with a 15-foot shaft the velocity of the air-current is 1,370 feet per minute, and the total quantity of air passing is 250,000 cubic feet. In another pit where the depth is 287 yards and the diameter of the shaft 9 feet, the velocity of the air is 1,692 feet. In a third pit, with a depth of 400 yards and a 15-foot shaft, the velocity is 1,640 feet, and the total quantity of air passing is 295,000 cubic feet per minute. Taking a 15-foot shaft with 300,000 cubic feet of air passing per minute, the velocity would be 1,666 feet per minute, which is not at all an abnormal figure. In the case of a volume of 400,000 cubic feet per minute, with a 15-foot diameter shaft, the velocity would be 2,220 feet per minute; while in an 18-foot shaft, with the same quantity of air passing per minute, the velocity would be 1,600 feet per minute. Summarizing these figures, one can safely say that with any 15-foot shaft 300,000 cubic feet of air per minute can be circulated at a not unreasonable velocity.

The President, I notice, also considers that a smaller shaft would require a longer time in sinking. I do not agree with that opinion, and can say that I have had tenders for sinking a smaller shaft at a much less figure than for a larger one. I think that the contractors would not overlook the point made by the President, but whether they are right or whether he is I do not know. Certainly, I do not think that there would be a tendency to have a big increase in costs by adopting a smaller shaft.

The President advocated four instead of two rubbing-guides for a pit 700 yards deep. We have at our pits a clearance of about 11 inches, and have two rubbing-guides, which are perfectly satisfactory, and I do not see the necessity for having two more.

Mr. Dickinson mentioned that the clearance at Hickleton Main Colliery is only $\frac{1}{4}$ inch. I must say that I am surprised to hear this, and I should certainly prefer to have more clearance than that. In such a case the rubbing would be on the guides all the time.

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 125.

The main object of the paper was to induce all those interested in the subject to consider whether, in the past, we have not been rather too lavish in the size of our shafts. Where a pit is put down to produce from 2,000 to 3,000 tons of coal per day, very good results can be obtained by working both shafts during one shift and one shaft during the other shifts. We did that, but it was, of course, due to the fact that we had not sufficient men to work both shifts at both shafts. When it is found that the difference in the cost of two shafts of 15 feet and two of 18 feet is the difference between £169,000 and £225,000, or £56,000, the matter is worthy of consideration, and one is strongly tempted to cut down the size of the shafts which we have been in the habit of sinking in the past.

Mr. J. Bircumshaw (East Kirkby), in reply to the President: There are three shafts at Kirkby, two downcast and one upcast. The velocity of 1,670 feet per minute applies to the upcast shaft, which is 15 feet in diameter.

DISCUSSION OF MR. N. E. WEBSTER'S PAPER ON "ELECTRIC WELDING OF A CAST-IRON ROPE-DRIVE FLYWHEEL."*

Mr. N. Baster (Nottingham): This paper brings before us another point in the application of electricity to colliery work. The amount saved—representing the difference between £84 and £400—though substantial in itself, might be insignificant when compared with the sum saved through the quickness with which a repair can be completed. The ease with which, in case of emergency, the process can be applied on the spot without dismantling the machinery, and the consequent saving of time, are features that are certain to be appreciated by all mining engineers. The system referred to by Mr. Webster is known to electrical engineers as the "plastic-arc" process. I think, however, that to-day in most systems the job is made positive and the electrode negative, although in the arc process when originally introduced the opposite was certainly the case. One of the chief reasons for the change was that as the direction of the current was from positive to negative, there was a tendency for the carbon of the electrode, either in the form of a vapour or in minute highly-heated particles, to be carried over to the work, and by entering into combination with the molten metal to alter its composition. This also was one of the reasons for the use of a flux, as it combined with any carbon thus projected, and so prevented its combination with the metal at the weld. The Wilson, or plastic-arc, system of welding was, I believe, used with much success in America during the war. A considerable amount of wilful damage was done, by their crews, to German ships interned in American harbours, in order to prevent their use for the transport of troops and materials to the theatre of war. The damage was chiefly to the cast-iron parts of the main engines, cylinders, piston-rods, connecting-rods, etc. Replacements and mechanical repairs would have taken a considerable time; but this system of electric welding having been suggested, it was tried, and with such success that the damage was speedily made good and the ships were able to be used for transport purposes. I understand that some of these ships have been in constant use since then without any failure of the affected parts.

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 136.

The PRESIDENT (Major T. P. Barber): We have started at our colliery an electric welding-machine, and find that there are many directions in which it can be used. A big heading-machine cracked right across, and it would have cost £40 or £50 to repair it, but the machine was made perfectly good in a couple of hours by one man. From our short experience of electric welding, it appears to be one of the most valuable adjuncts that we have at the colliery.

Mr. B. MCLAREN (Pye Hill): I mentioned at the last meeting that we had had an electric coal-cutting machine electrically welded after being broken across. I was not then acquainted with the system adopted, but I understand that it was the "quasi-arc" system. It is now two months since the machine was repaired, and it is working as satisfactorily to-day as if it were new.

Mr. G. W. DICKINSON (Clay Cross): There was great difficulty during the war in obtaining raw material, and the Clay Cross Company were glad to avail themselves of the opportunity of using this method of welding for building up and strengthening various articles that had broken down, but I cannot say that the results were satisfactory. In the case of tram-wheel axles, these in the main were simply filled in, and we found the process for that purpose rather useful. But we also found that when some of these electric welding firms were called in, their first object was to find out how much it would cost to get a new wheel, or a new part, and having ascertained that, they then quoted accordingly, so that we derived very little monetary advantage from giving the system a trial. My experience leads me to the conclusion that tensile strength cannot be guaranteed if electric welding be employed for building-up purposes.

Mr. W. HAY (Chapeltown): I have used this process extensively in repairing boilers, and in every instance it has proved very successful. The boiler inspectors in our district favour it in most cases. An immense amount of labour is saved in not having to take out the tubes.

Mr. J. BIRCUMSHAW (East Kirkby): Our experience of electric welding at Kirkby Colliery is quite different from Mr. Dickinson's. We have welded haulage-gear cast-iron spur-wheels quite successfully. We have also built up boiler-tubes, and repaired cage-hoops and other similar jobs. In the case of welding cage-hoops, a great saving is effected. New pit-cages to-day are very costly, and the welding of the cage-hoops adds considerably to the life of the cage.

We have also built up the grooves in the end-plates of two high-pressure boilers. Before doing this, however, we obtained a quotation for new plates, and this amounted to £89 per boiler, or £178 in all. We also got a quotation from a welding firm for carrying out the necessary repairs, their price being about £60. We then procured a price for an electric-welding set, which was £45. The firm in question offered to give a free demonstration, and we gave them the boiler-plates to build up. This they did very satisfactorily, but, as the work took them longer than they anticipated, an additional £5 was paid to them, thus bringing up the total cost to £50. Whilst this work was being done, two of our own workmen were trained in the use of the welding apparatus, and these men are now doing useful wo·k at the colliery.

Mr. G. W. DICKINSON: I do not wish to convey the impression that electric welding is of no value; my point is that it is more useful in

building up than in welding together pieces of iron so that the original strength shall not be impaired. Sometimes, too, it is of very great advantage to build up *in situ*. When that can be done, the cost is much less than taking down a wheel (such as a headgear pulley) or a machine needing repair and putting it together again, or replacing it by a new part.

Mr. N. E. Webster (Wrexham) wrote: Mr. Baster states that in most systems of electric welding the job is positive and the electrode negative, in order to avoid carrying over excess carbon, as occurs when the current is in the reverse direction. I imagine from this that he refers to the old systems of welding, in which the electrode consisted of a carbon stick, with which the arc was created, and which served to liquefy the metal, introduced by a separate wire inserted into the arc. This method did cause a great deal of carbon to be carried over, with consequent loss of tensile strength in the work done. In the Wilson system, however, all electrodes are carefully calibrated as regards their composition to ensure that only the requisite percentage of carbon shall be carried over, there being ten different grades of iron-carbon electrodes. The reversal of polarity would, therefore, have no effect, so far as the resultant composition of the metal is concerned, but the penetration would be considerably less, with consequent loss of strength in the weld, and with the tendency for the added metal merely to form a skin over the surface of the job.

With regard to Mr. Dickinson's point that tensile strength cannot be guaranteed if electric welding be employed, I agree that a great many welders do not and cannot guarantee that the job shall retain the strength of the original metal. With the Wilson system, however, a guarantee is given with the job; in fact, this is the only firm of welders to my knowledge who will guarantee welds of cast-iron. In order to illustrate the fact that tensile strength is retained, I would refer to the welding of the propellor-shaft of the 4-ton lorry mentioned on page 139. An even more illustrative case that has occurred since the writing of this paper is the welding of the cutting-bar of a Mavor-&-Coulson electric bar coal-cutting machine. This bar, which snapped at a point two-thirds distant from the extreme cutting-point, was welded with a special grade of electrode, and has since been put to work again. It has not yet stood for a great length of time, but it has cut a considerable number of yards of coal without there being any indication of the likelihood of trouble.

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS, 5, JOHN DALTON STREET, MANCHESTER, DECEMBER 13TH, 1921.

MR. SYDNEY SMITH, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were elected :—

MEMBER—

Mr. JOHN J. MCDOUGALL, Stellarton, Nova Scotia.

ASSOCIATES—

Mr. JAMES BAINES, 285, West End Road, Haydock, St. Helens.
Mr. WILLIAM COCKER, Laurel Cottage, Greenheys, Little Hulton, Bolton.
Mr. THOMAS STANLEY GRUNDY, 17, Downall Green Road, Bryn, Wigan.
Mr. EDWARD MARSH, Havannah Colliery, Parr, St. Helens.
Mr. FRANK B. HOWITT, 242, Nutgrove Road, St. Helens.

Mr. W. T. Anderson, M.I.E.E., read a paper, illustrated by lantern-slides, on "The History of a Colliery Cable (from Factory to Face)."

THE MANCHESTER GEOLOGICAL AND MINING SOCIETY.

GENERAL MEETING,
HELD IN THE ROOMS OF THE SOCIETY, QUEEN'S CHAMBERS, 5, JOHN DALTON STREET, MANCHESTER, JANUARY 10TH, 1922.

MR. SYDNEY A. SMITH, PRESIDENT, IN THE CHAIR.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were elected :—

ASSOCIATE MEMBERS—

Mr. RODERICK HARRY PARNELL, c/o Burmah Oil Company, Limited, 101, Clive Street, Calcutta, India.
Mr. W. D. GREY REES, 16, Bosworth Road, Skewen, Neath.
Mr. HAROLD EGERTON SPEAKMAN, The Walmsleys, Leigh.
Mr. JOHN WILLIAM THOMAS, Rydal House, Frizington, Carnforth.

ASSOCIATES—

Mr. MATTHEW GAVAGHAN, 65, Clyde Street, St. Helens.
Mr. RALPH COWBURN HARRISON, Old Sirs Farm, Daisy Hill, Westhoughton, Bolton.

Dr. Edward Greenly delivered a lecture, illustrated with lantern-slides, on "The Ancient Rocks of Anglesey known as the Mona Complex."

THE MINING INSTITUTE OF SCOTLAND.

EXCURSION MEETING,

Held at the Flemington Electrical Works, Motherwell, November 17th, 1921.

About one hundred members of the Institute visited the works of Messrs. Anderson, Boyes, & Company, Limited, electrical, mining, and mechanical engineers, Motherwell, and were received by Mr. Alexander Anderson (Managing Director) and Mr. James B. Shield (Director and Works Manager).

The members made an inspection of the works, and witnessed the process of manufacture of coal-cutting machines and mining switch-gear.

Prof. Daniel Burns (Royal Technical College, Glasgow) carried out experiments relative to the safety of electric plant in the presence of gas in mines.

Mr. David M. Mowat (Past-President) moved and Mr. George Gibb seconded a hearty vote of thanks to the company for their kindness in receiving the members at their works, the visit having proved highly interesting and instructive.

Mr. Alexander Anderson acknowledged the vote.

THE MINING INSTITUTE OF SCOTLAND.

GENERAL MEETING,

Held at the Royal Technical College, Glasgow, December 10th, 1921.

Mr. ROBERT McLAREN, M.P., President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen, having been duly nominated, were declared elected :—

Members—

Mr. Alexander Bauld, Colliery Manager, Ravenscraig, Saline, Oakley, Fife.

Mr. Blyth Davidson, Colliery Manager, Helendhu, Kinglassie, Cardenden, Fife.

Mr. Charles Hunter, Under-manager, Kinglassie Cottages, Kinglassie, Cardenden, Fife.

Mr. James Peacock, Colliery Manager, Birkrigg Colliery, Dalserf, Lanarkshire.

Associate Members—

Mr. John Richardson Stuart, Mining Engineer, 17, Rosevale Street, Partick, Glasgow.

Mr. Joseph Thomson, Colliery Manager, Ghugus Colliery, District Chanda, India.

Mr. Archibald Wilkie, Junr., Mining Engineer, Temperance Hotel, Kirkconnel, Sanquhar, Dumfriesshire.

ASSOCIATES—

Mr. DOUGLAS ALEXANDER ALLAN, B.Sc., Assistant Lecturer on Geology, 18, Shandon Place, Edinburgh.

Mr ROBERT HARCUS, Mining Student, 119, Dudley Avenue, Leith, B.O., Edinburgh.

Mr. ROBERT LOUIS ALEXANDER DRON, Mining Student, Utica, Bearsden, Glasgow.

Mr. GEORGE STEWART SCOTT DUNS, Mining Student, 26, Newtown Street, Duns.

Mr. JAMES MCADAM, Mining Student, 18, Camperdown Road, Aberdeen.

Mr. DAVID MAXTON WOTHERSPOON, Mining Student, Silverdale, Craighall Road, Edinburgh.

INAUGURATION OF A STUDENTS' SECTION.

The PRESIDENT: Since we last met together a section for mining students in connexion with this Institute has been formed, and office-bearers have been appointed. The purpose of this section is to encourage our young men to study the various scientific questions associated with mining operations, and by and by we hope that those identified with it will become useful and active members of the Institute, and take a prominent part in its deliberations. It was felt by the Council that these young men did not get a proper opportunity of ventilating their views and of discussing problems of interest and difficulty, and it was thought that the idea of a students' section would prove beneficial and acceptable. We ought to take advantage of every opportunity to encourage our young mining men in their work and studies. By using our brains in that direction, I am sure that we shall be able to bring this old country of ours back to the proud position it occupied for so many years when it stood first in the advancement of scientific knowledge in the operations of mining.

DISCUSSION OF MR. DAVID PENMAN'S PAPER ON "A NEW METHOD OF MEASURING VENTILATING RESISTANCES, WITH SPECIAL REFERENCE TO THE OPERATION OF MINE FANS IN COMBINATION."*

Mr. DAVID PENMAN (Dhunbad, India) wrote: I have to thank Mr. Parker for his kind remarks regarding my paper. In reply, I may say that when I wrote the paper I was, of course, acquainted with the fact that electrical analogies had already been used in the elucidation of ventilation problems; indeed, I referred to this point on the first page of the paper. Nevertheless, so far as I am concerned the method of treatment is original. I was not aware, however, that the proposed unit for estimating the ventilating resistance of a mine was not new; but I think I am right in stating that it has not previously been suggested in any paper read before the Institute.

In the treatment of ventilating resistances in series and in parallel I preferred to keep to the single conception of resistance throughout, my object being to suggest that it was preferable to speak of the *resistance* of a mine rather than of its *conductance*, which is the method of the equivalent orifice. From a teacher's point of view it has often struck me that, in comparing one mine with another from their equivalent orifices, the student has to go through a sort of mental gymnastics,

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., pages 39 and 85.

which would be avoided if the ventilating resistances of the mines were stated directly instead of inversely.

With regard to Mr. Parker's other remarks, I think the paper shows clearly that the advantage to be gained from running fans in parallel will be slight unless the internal resistance of the fan approximates to or exceeds the resistance of the mine, which is very exceptional. I think, with Mr. Parker, that provided the internal resistance of the fans is relatively small compared with the resistance of the mine, fans in series can be quite profitably employed.

I agree with Mr. Mavor that it would be a distinct advantage to have a standard method of carrying out fan tests and a uniform method of recording the results. Until methods of testing have been standardized, results of investigation must inevitably continue to be presented according to the individual views of the investigator.

In reply to Mr. Kerr, with regard to the omission of any reference to underground auxiliary ventilation, the paper was already so long that I did not think it advisable to discuss that phase of the question. I agree with him in thinking that there are many problems relating to underground fans on which useful investigation might be made. The subject, however, is one which would require a paper to itself.

I do not agree with Mr. Kerr that the adoption of the suggested unit of resistance would tend to confusion rather than simplicity. It would not be at all necessary for the student to learn the equivalent-orifice method as well. The size of the opening indicates the inverse of the mine resistance. Why not measure the resistance directly? It is only a matter of choosing a suitable unit. The desired result would be obtained from the same measurements, namely, water-gauge and quantity, as are required in order to arrive at the equivalent orifice.

With regard to Mr. Kerr's suggestion that I should have dealt with practical suggestions for the reduction of mine resistances, that again, unless it were simply to consist of statements with which everyone agrees, might very well form a separate paper. He has himself made quite a number of useful suggestions; indeed, his whole contribution forms a valuable supplement to my paper.

Mr. Kerr objects to the terms of some of my conclusions. I do not see that there is much wrong with No. 3. While it is quite true that "no mining engineer would think of installing a fan with a resistance equal to one-third of the resistance of the mine," it is equally true that there are instances in British mining where during the lifetime of the colliery those conditions have been approached. But, of course, my object in making the statement was simply to define the point at which it might become worth while to run fans in parallel. Anyone wishing to see what may be expected on either side of that point can obtain that information from the calculations in the paper.

The criticism of conclusions Nos. 4, 5, 6, and 7 may be taken as a whole. Take the case of a fan the internal resistance of which is small compared with that of the mine, which as Mr. Kerr remarks is as it ought to be. Let a second and similar fan be installed. My calculations show that if the two are run in parallel at the same speed as that at which the single fan was run, the increase in quantity will be very small indeed, but that if they are run in series the increase in quantity obtained will approximate to 35 per cent.

A careful study of the figures given in Tables II. and III. will give Mr. Kerr the information he requires to amplify the conclusions to which he takes exception. I regret that owing to the arrangements at the

Wellesley Colliery I was not able to run the two fans in series. If this could be done under the same conditions with respect to fan and mine resistances as obtained at the time of the series of tests taken by me, I have not the slightest doubt but that the increase in quantity obtained would come very near to the figure I have given as a probable one, namely, 35 per cent.

I fail entirely to see why the Guibal fan should behave differently from other types of fans, and I do not think that Mr. Kerr's remark that with the Guibal fan practically no increase at all would be obtained is correct.

Mr. Kerr takes me to task over the capacity of the Sirocco fan. I must admit that I was slightly in error there, although not to the extent that his remarks would lead one to believe. I had, of course, obtained the particulars of the capacity of the fan from the makers. I am speaking from memory, but I think the figure they gave was in the neighbourhood of 280,000 cubic feet per minute on an opening of 56·67 square feet, and with a water-gauge of 4 inches. I should have given this figure separately for the Sirocco fan instead of including both fans in one statement.

Mr. Kerr will understand that his reference to water-gauge in this connexion has no meaning whatever, as according to a well-known law the quantity increases as the square-root of the water-gauge. If the quantity of air delivered by a fan is 280,000 cubic feet per minute with a water-gauge of 4 inches, it would be in the region of 400,000 cubic feet with a water-gauge of 8 inches. While admitting the slight error referred to, I think I am entitled to point out that it was unnecessary, and indeed erroneous, to include a reference to the water-gauge.

I am in agreement with Mr. Kerr, Mr. Dron, and the President, who also refers to the matter, that the Committees appointed by the Institute some years ago should now go into the question of a standard method of carrying out ventilation tests, and I thank Mr. Kerr for the suggestion that the unit method of comparing relative resistances might be adopted by that Committee.

Mr. Kerr suggests that I should have adopted a standard peripheral speed—say, 1,000 feet per minute—throughout the tests. If I had done so, I might, as Mr. Kerr remarks, have obtained some interesting information as to the output capabilities of the two fans in regard to quantity and water-gauge. But that was not the purpose of the paper. Moreover, an entirely different series of tests would have to be carried out. The comparative output, capabilities, and efficiencies of a fan are doubtless a subject of great interest, and a great deal of work remains to be done on this phase of fan ventilation.

The tests taken by me would seem to indicate that for the same peripheral speed the Sirocco fan gives a higher water-gauge in the fan-drift than does the Waddle fan. For example, as Mr. Kerr points out, 4·2 inches of water were recorded in the fan-drift with the Waddle fan running alone at a peripheral speed of 137·77 feet per second, while the Sirocco fan with a peripheral speed of only 90 feet per second gave a water-gauge of 4·1 inches. It is likely, I think, that the Waddle fan has a higher internal resistance than the Sirocco fan, and that in the former the kinetic energy in the air is not so completely converted into pressure as is the case in the Sirocco fan. But possibly the chief reason for the high water-gauge produced by the Sirocco fan lies in the shape of its blades.

In conclusion, I would like to thank Mr. Kerr for the evidence of the

great interest he has taken in my paper and for the valuable comments he has made on it. His contribution bristles with suggestions of ventilation problems on which much useful experimental work remains to be done.

Prof. Henry Briggs (Edinburgh) wrote: This is one of the most important papers the Institute has had before it for some time; it deserves very careful consideration, because it contains several valuable suggestions and develops a line of attack upon certain problems of ventilation which stand badly in need of intelligent treatment. The fact is that much of the subject of mine ventilation requires drastic revision. It is packed with antiquated "Aunt Sallys" whose sole purpose in life is to provide material for questions in the examinations for the Colliery Manager's certificate. Mr. Penman is to be congratulated on his attempt to topple a few of these over. Murgue was, of course, the chief culprit in this respect; his book on *The Theory and Practice of Centrifugal Ventilating Machines* is full of false reasoning. One of his much-prized results, for example, depends upon his inability to conceive of an angle over 90 degrees. Again, his manner of finding the "orifice of passage" of a fan rests upon a fallacy; as Mr. Penman has pointed out,* a fan with blades bent forward does not produce its maximum depression when the fan-drift is completely closed. Sometimes the depression, when air is being delivered, is considerably larger than the "initial depression." If Murgue's method of evaluating the orifice of passage of such a fan be followed, the obviously absurd result of a negative orifice is obtained.

It is time these "orifices" passed into limbo. When the electrical engineer wishes to state the resistance of a circuit, he does not begin by asking one to consider the circuit removed and an imaginary air-gap (shall we say) put in its place. He has got far beyond the stage of depending on clumsy analogues to express his meaning: he gives the resistance in ohms.

Really all that Mr. Penman asks is that we should go and do likewise; he shows that if a ventilation resistance unit be adopted, certain problems concerning fans become easy to state and easy to solve. Unfortunately, he has no name for such a unit, and a name it must have before it can be readily defined and handled. The electrical engineer has immortalized a number of great physicists and engineers by attaching their names to his units, and it seems to me that we might follow his lead. The names of several men who have benefited mining, and in particular that of the great Yorkshire engineer who recently died, will occur to the mind; they have a claim to perpetuation as great in their own sphere as Coulomb, Ohm, and Ampère.

To compare an electrical and a ventilating circuit, as Mr. Penman himself states, is not a novel idea; but he has drawn more from the analogy than any previous writer, and has developed a number of useful and simple relationships, based on his central conception of a specific unit of resistance. I can find no flaw in the reasoning leading to these relationships, if it be granted that the difference of pressure inducing flow divided by the square of the air-volume is a constant both in the case of the mine and in that of the fan itself.

Just before completing his paper Mr. Penman was appointed Principal of the School of Mining and Geology in Bengal; he had to leave home at short notice, and was thus unable to carry out all the experiments that he had planned. For this reason the latter part

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 50.

of the paper is of less value than the first. Nevertheless, it is of great interest, especially as showing the nicety of speed regulation needed when fans operate in parallel.

Mr. James Hamilton (Glasgow): Mr. Penman must have spent much time over his useful and laborious investigation, but much of the space occupied by the paper is wasted on the analogy between electric resistance and air-current resistance. Such analogies are rarely of any value. Nothing is deduced from them. All his results are based on the known laws applicable to air-currents.

I hardly think Mr. Penman has made good his claim to a "new method of measuring ventilating resistance." It is expressed in new units, but that is all. It does not appear any simpler, or more easily used, than the equivalent-orifice; but it has this one virtue: it deals with a direct instead of an inverse ratio.

Most, if not all, of his conclusions on pages 56 and 58 could have been deduced from the known laws of ventilation without his experiments of long investigation. His conclusions are not likely to be seriously questioned for that reason. The use of fans, either in parallel or in series, must result in a lower efficiency, just as it is an expensive method of increasing ventilation by increasing the water-gauge.

There are some curious results, or even anomalies, in Table III. For example, in experiment No. 4, with a speed of the tips of the blades of 89 feet per second in the Sirocco fan, the same water-gauge is given as that for a speed of 145 feet in the Waddle fan. Again, in that same experiment, with equal water-gauges recorded for the two fans, air is drawn through the Sirocco fan to the Waddle fan, whereas in the following experiment, with a difference of water-gauge between the two fans of 0·05 inch, the quantities are nearly equally divided. In experiment No. 6, with a difference of 0·1 in its favour, the Sirocco fan takes five-sixths of the quantity. There may be an explanation apart from error in the observations, and it would be well to have it. One cannot help wondering whether a mistake has been made in the recorded speed of the Sirocco fan.

The quantity of air delivered by the Sirocco fan when working alone in experiment No. 9 agrees almost exactly with that delivered by the Waddle fan in experiment No. 1, allowing for the difference in water-gauge, and it agrees fairly closely with that of No. 8 on the same basis. But in experiments Nos. 5 and 6 the quantity delivered is about $9\frac{1}{2}$ per cent. greater than is explained by the difference in water-gauge.

In Table IV. it is claimed that in the three cases given the increase in quantity due to running fans in parallel is 21, 15, and 9 per cent. respectively. The fact is, no doubt, as stated, but in the first two cases the pressure is so much increased that the actual increases in quantity are minus instead of plus—that is, in the first the quantity increase is 4·8 per cent. less than is accounted for by the increase in water-gauge, and in the second 2·3 per cent. In the third case the increase above what is accounted for by the increased pressure is about 7·8, and not 9·3 per cent. as claimed.

The experiments are incomplete, in respect that no test of the power expended in driving the fans is made. The power required would, no doubt, be less for each if the two fans are running in parallel than it would be for each running alone; but without knowing how much less, it is impossible to say certainly that the two fans working together in parallel add to or detract from the efficiency.

In the last paragraph but one on page 55 the words "increases" and "decreases" are apparently transposed. As the mine develops the ventilating resistance will increase and its equivalent orifice decrease.

Mr. John B. Thomson (Hamilton): Some of the speakers at a former meeting remarked that the author's idea is not new, but I think that he is to be complimented on making use of the ventilating resistances in estimating what two fans working together would do. It was a happy thought that struck him, as such an analogy to an electric current could not have been made with the usual system of equivalent orifices.

The results that Mr. Penman has arrived at are, however, so surprising that I suspect there is some fallacy in his algebra, but if there is, I confess I am not able to put my finger on it. Taking the case of the two fans running in series as argued on pages 42 and 43, is it the case that R is the same for both fans when running singly and when running in series? Consider one fan running at a certain speed and producing a certain quantity at a certain water-gauge through the mine. It discharges the air into the ear of the other fan at a positive water-gauge at least equal to the water-gauge due to the velocity. If the fan were discharging its air in the normal way through an évassé chimney, there would be a water-gauge at the very top of the chimney precisely equal to the water-gauge due to the velocity of the air and which is required to dissipate the velocity in the still atmosphere. Now the second fan has a great deal of leeway to make up. It will require to be driven at a speed to get rid of this positive water-gauge and the speed increased to practically the speed of the other fan before it will be assisting it in any way. I would be surprised, therefore, if the two fans would give the increased quantities that Mr. Penman calculates.

Mr. Kerr suggests that it would have been of value if Mr. Penman had indicated the engines when making the tests of the fans at Wellesley Colliery, and I would suggest that if Mr. Penman has time he might do the tests over again and give us a supplementary paper with the results, as there is no doubt what interests practical engineers in these days is the economic side of the question. It did not come within the scope of the author's paper, but, as I say, he might be induced to carry his tests a little further, or, perhaps, another way would be for the Committee that was appointed to fix a standard method of testing conditions to extend their labours and consider this subject and co-opt Mr. Penman to look after that side of the question.

Another point in Mr. Penman's paper which I have a diffidence in approaching, but which Mr. Penman in his reply to the discussion might amplify a little, is his statement on page 50 that the theoretical water-gauge of fans with blades curved backwards or forwards is influenced by the quantity of air passing through the fan. On the previous page he gives the formulæ for calculating the theoretical water-gauge, these being deduced from the well-known formula $v = \sqrt{2gh}$. It is a calculation to find the theoretical height a particle would attain with an initial velocity before coming to rest. I do not see how this calculated amount can be influenced by the shape of the blades of the fan. I have tested quite a number of fans, all I think with forward curved blades, and have had on several occasions the fan-drift closed up in order to get the initial water-gauge, and I have never noticed an increase on the fan-drift water-gauge when opening up the stopping. The water-gauge that is measured in the fan-drift is a measure of the resistance that the air passing has encountered up to that point, and this is constant so long as the con-

ditions are the same; it does not matter whether the depression is caused by one fan or two fans, or other means of producing it. I would, therefore, like Mr. Penman to give some further explanation in support of his statement.

The discussion of the paper was closed.

DISCUSSION OF MR. JAMES COOPER'S PAPER ON "THE TESTING OF ANEMOMETERS."*

Mr. James Black (Shettleston, Glasgow): Mr. Cooper is to be congratulated on having placed before the members so interesting a paper dealing with a subject which, although of considerable importance, has been very much neglected in the past. The calibration of anemometers has certainly not received anything like attention commensurate with its importance. Doubtless the lack of proper facilities for experimental work is largely responsible for this state of affairs, and Prof. Briggs's enterprise in designing and constructing an anemometer testing-table for use in the Heriot-Watt College, Edinburgh, is worthy of the highest praise.

Since the Coal Mines Act of 1911 came into force, it has been necessary at least once in every month to measure the quantity of air in each ventilating district at or as near as practicable to a point 100 yards back from the first working-place at the working-face which the air enters. Now it is well known that even in a well-ventilated mine it is quite impossible in most cases to determine with any degree of accuracy the velocity of the air-current within an even greater distance than 100 yards back from the first working-place. Either the vanes of the anemometer, because of the low velocity, will fail to revolve or the reading obtained is erroneous.

It has always appeared to me as not being outside the realm of possibility to design and construct an anemometer which would be more sensitive in its action, and consequently better adapted for measuring velocities of from 300 feet per minute downwards.

In 1908 I read a paper before the Scottish Federated Institute of Mining Students entitled "Testing a Centrifugal Fan." When dealing with the measurement of the air-current I made the following observations, which may be of interest in connexion with the subject under discussion:—

"The measurement of the air-current is undoubtedly a great source of error, and it is extremely probable that the quantity is exaggerated in many tests The anemometer is the best instrument we have at the present time for measuring the velocity of an air-current, but it is very liable to lead to wrong conclusions, unless great precaution is exercised. It was proved conclusively by the Prussian Mining Commission in 1884 that an anemometer which has been calibrated by rotating it at the end of a radius bar, driven at a uniform rate, exaggerated the velocity of a uniform flow of air by about 10 per cent. This is probably due to the fact that the air in which the anemometer is tested does not remain still, as is assumed, and consequently the velocity indicated by the instrument is less than the distance through which it has been moved. When an anemometer is used to measure the very irregular velocity of the air in a fan-drift, a still greater exaggeration is produced unless great care is taken to manipulate the instrument in such a manner as will avoid its being moved too rapidly over areas having widely different velocities.

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 90.

That this is the case may be demonstrated clearly in the following manner:—Take a wooden rhone of such a length and cross-sectional area as is found most convenient. Divide the rhone longitudinally, by means of a thin partition, into two separate compartments. Arrange in some way for a brisk current of air to pass through the two compartments simultaneously. Regulate one of the currents until its velocity is considerably less than that of the air passing through the adjoining compartment. Standing near to the delivery end of the rhone, hold the anemometer in each of the air-currents for, say, one minute. Note the velocity, divide by two, make the necessary allowance for friction, and the result is the average rate of flow in feet per minute. Next hold the anemometer in each of the air-currents alternately for equal short periods, and allow it to run for two minutes as before. Determine the average velocity, in feet per minute, as in the last test. In comparing the results, it will be found that they are widely different, and it may be mentioned that the greater the difference of velocity the greater will be the difference of the results. The average velocity as determined by the latter method will be the higher. This is probably due to the anemometer taking a longer time to lose its speed than to acquire it. It is evident from this that anemometer readings must be accepted with caution. The anemometer is a rather delicate instrument, and is easily deranged, even with careful usage. For this reason they should always be calibrated previous to making an important test."

The President (Mr. Robert McLaren): Those who have tested anemometers in low velocities must conclude, I am sure, that it is quite impossible to secure accurate results. For many years I took about with me two anemometers of the Biram type, and I found that when I reached within 50 yards of the face they were of little practical advantage in testing. The difficulties which arose in that way called forth the question—is it of any advantage at all to use an anemometer for testing in a certain velocity of air? I have discovered, notwithstanding what Mr. Cooper states about the smoke test, that as a practical man I have succeeded in low velocities in obtaining more accurate results from such a test than from the anemometer. My own belief is, as a result of my experience, that if there be uniformity at all the smoke test will not go very far astray, provided that accuracy is maintained up to the time when the smoke is felt. I of course agree that a great deal depends on a man's nose and sense of smell. I join issue in some points with the author of the paper, and hold that the larger the vanes of the anemometer the better the results are likely to be, provided that an instrument sufficiently delicate to deal with a small quantity of air is used. Mr. Cooper speaks of the formation of a vacuum, and that, I believe, does take place. Those who have had any experience of a coal-dust explosion will recall that on the side opposite where the force comes will be found the fine dust caused by the vacuum behind the props. The same thing happens in a storm, especially in the case of snow; as the snowflakes come down, the part facing the storm is perfectly dry and smooth, but behind that the snow lies, because the vacuum has made a place for it.

The further discussion of the paper was adjourned.

THE OPERATION OF FANS IN PARALLEL.

By JOSEPH PARKER, B.Sc.

In the published papers on the results of running fans in parallel, it would appear that the authors are of opinion that the speed of such fans should be so regulated as to remain the same as when the fans are running singly. The experiments have been carried out with but a small variation of the speed from the normal speed of one fan running alone.

There appears to have been an expectation that two duplicate fans, running in parallel, but at no increase of speed, would draw a greatly increased volume of air from the mine, despite the well-known laws of ventilation, which define the relations between the quantity and the pressure and between the speed of the fan and the pressure. The results obtained are very useful in the support they give to those laws.

Only upon the assumption that the internal resistances of the fans are abnormally large can it be shown that a slightly increased volume results.

The obscession for maintaining a constant-speed regulation is clearly shown from the eighth conclusion arrived at by Mr. Penman in his paper on "A New Method of Measuring Ventilating Resistances,"* where he states that "The satisfactory running of two fans in parallel can best be accomplished through the medium of synchronous electric motors."

Two fans running in parallel on a speed regulation are like two alternators running in parallel on bus-bars; but while the reactances of the alternators exert a powerful synchronizing effect on the alternators, which keeps them in step, there is no corresponding synchronizing factor in the case of fans. The only synchronizing factor in such a case is their internal resistances, which is analagous to the ohmic resistance of the alternators; and it is well known that if it were possible to construct alternators with ohmic resistances only, they would not operate satisfactorily in parallel.

But it appears to me that this obscession for constancy of speed has hitherto obscured the field for the useful application of fans working in parallel. Suppose we turn our attention from the problem of speed-regulation to that of power-regulation, and that, instead of arranging for constant speed, we arrange for our fans to develop constant power.

If electric motors are used for driving the fans, we shall find that instead of the shunt-motor or the synchronous motor we should use either a direct-current series-wound motor or a single-phase motor having a series characteristic.

If we have a steam drive, we could have either a Meyer valve-gear arrangement, and we should adjust the cut-off valve to cut off earlier when the speed was higher, so as to give a proportionately lower mean effective pressure; or we might have drop-valves, and a means of progressively earlier cut-off as the speed rose.

* *Trans. Inst. M. E.*, 1921-1922, vol. lxii., page 39.

If we have made the arrangements to secure constant power, we can then study what results would follow.

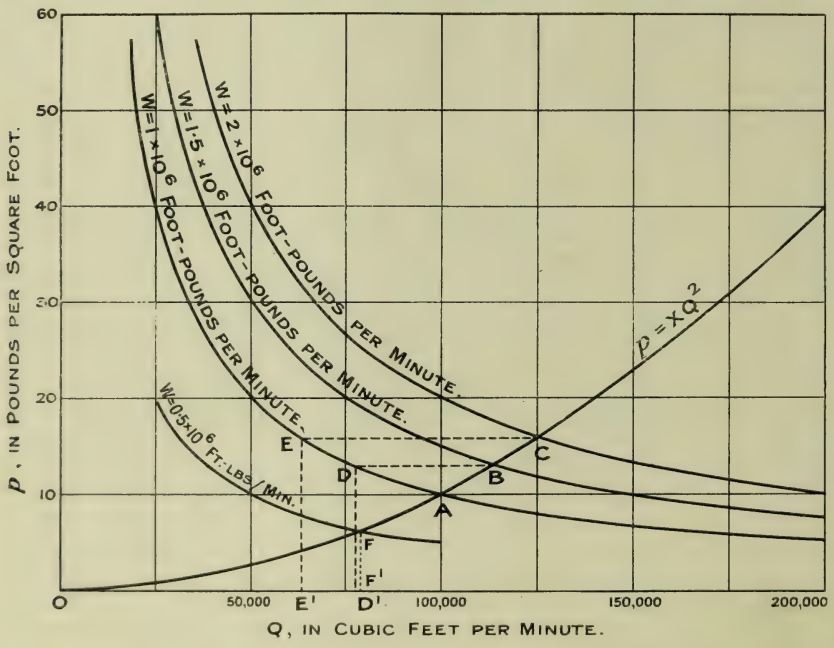
Suppose we have a fan running on a mine and passing 100,000 cubic feet of air per minute with a ventilating pressure of 10 pounds per square foot: the work done on the air will be $10 \times 100{,}000 = 10^6$ foot-pounds per minute.

For the mine we shall have the relation between pressure, quantity, and mine resistance expressed by $p = \frac{ks}{a^3} \times Q^2$; and writing $\frac{ks}{a^3} = X$, we may express these relations thus :—

$$p = XQ^2.$$

In our example we have $p = 10$ and $Q = 100{,}000$; hence $x = 10^{-9}$, or $p = 10^{-9} Q^2$.

In the figure in the text the graph of $p = XQ^2$ is plotted for the axes p and Q. Also the curve "work done" $= 10^6$ foot-pounds per minute,



and two other similar curves for "work done" $= 1{\cdot}5 \times 10^6$ and $W = 2 \times 10^6$ foot-pounds per minute respectively.

The point A, in which the two curves $p = XQ^2$ and $W = 10^6$ foot-pounds per minute intersect, represents our working condition when one fan is running and passing 10^5 cubic feet per minute with a pressure of 10 pounds per square foot.

If now we have a duplicate fan driven by a motor of equal power, and we set it to work in parallel with the fan already working, the total work done will be 2×10^6 foot-pounds per minute, and our working conditions will be represented by the point C where the curve $p = XQ^2$ intersects the curve $W = 2 \times 10^6$ foot-pounds per minute. The volume of air passed will have increased to about 126,000 cubic feet per minute and the ventilating pressure to about 15·8 pounds per square foot.

The point E represents the condition under which each of the fans is working. EE^1 = the pressure, and OE^1 the volume passed by each fan.

Suppose now that the incoming fan is driven by a motor of one-half the horsepower of the running fan: the total power developed would now be $1{\cdot}5 \times 10^6$ foot-pounds per minute, and the point B, where the curve representing this power cuts the curve $p = XQ^2$ will now represent the condition of affairs.

The point D (obtained by drawing a horizontal line through B to intersect the curve EDA) will represent the conditions in the more powerful fan which will pass a volume represented by OD^1 at a pressure represented by DD^1. The volume passed by the incoming fan will be represented by DB. The total volume will be about 114,000 cubic feet per minute, of which the incoming fan will take one-third.

This suggests a useful field for the application of fans in parallel; for by controlling the power developed, instead of the speed, we can quite conveniently add to the power of the existing ventilating appliance.

At week-ends, and at times when the pits are not working, the ventilating current can be safely reduced in many cases. In the case we have just considered, if we were to put the smaller fan, developing $0{\cdot}5 \times 10^6$ foot-pounds per minute, to work at week-ends, we should still obtain about 80,000 cubic feet of air per minute, which would probably be ample; while, when both fans were working, we should obtain 114,000 cubic feet per minute during the period when the pits were working.

These considerations show us that it is the power and not the speed that should be regulated; they also show that there is a decided field of usefulness for the application of fans running in parallel.

THE INSTITUTION OF MINING ENGINEERS.

SUBJECTS FOR PAPERS.

The Council of The Institution of Mining Engineers invite original communications on the subjects enumerated in the following list, together with other questions which are of interest to mining engineers.

Boiler explosions.
Bore-holes and prospecting, including methods of boring.
Brickmaking by machinery.
Brine-pumping.
Canals, inland navigation, and the canalization of rivers.
Coal-getting by machinery.
Coal-washing machinery.
Coke manufacture and the recovery of bye-products.
Colliery leases, and limited liability companies.
Compressed air as a motive power.
Corrosive action of mine water on pumps, etc.
Descriptions of coal-fields and other mineral deposits.
Distillation of oil-shales.
Duration of coal-fields of the world.
Electric mining lamps.
Electricity and its applications in mines.
Engine-counters and speed-recorders.
Explosions in mines.
Explosives used in mines.
Faults and veins.
Fuels and fluxes.
Gas-, oil-, and petroleum-engines.
Gas-producers and gaseous fuel and illuminants.
Geology and mineralogy.
Haulage in mines.
Industrial assurance.
Inspection of mines.
Laws of mining and other concessions.
Lead-smelting.
Light railways.
Lubricating value of grease and oils.
Lubrication of trams and tubs.
Maintenance of canals in mining districts.
Manufacture of fuel-briquettes.
Mechanical ventilation of mines, and efficiency of the various classes of ventilators.
Mining of mineral deposits.
Natural gas: its conveyance and uses.
Occurrence of mineral ores, etc.
Ore-sampling and sampling machines.
Petroleum-deposits.
Preservation of timber.
Prevention of overwinding and accidents in shafts.
Pumping machinery.
Quarries and methods of quarrying.
Rescue-work.
Rock-drills.
Safety-lamps.
Screening, sorting, and cleaning of coal.
Shipping and discharge of coal-cargoes.
Sinking, coffering, and tubbing of shafts.
Spontaneous ignition of coal and coal-seams.
Steam-condensation arrangements.
Steam-power plants.
Submarine coal-mining.
Subsidences caused by mining operations.
Surface-arrangements at mines.
Surveying and surveying instruments.
Transport on roads.
Tunnelling methods and appliances.
Underground conveyors.
Utilization of dust and refuse-coal.
Ventilation of coal-cargoes.
Water as a motive-power in mines.
Water-incrustations in boilers, pumps, etc.
Water-tube boilers.
Watering coal-dust.
Winding arrangements at mines.
Winning and working of mines at great depths.

The Council, if they think fit in any year, may award medals or other awards to the author or authors of papers published in the *Transactions*, or to persons who have distinguished themselves by their contribution to the advancement of mining and other branches of technology.

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THE NORTH OF ENGLAND INSTITUTE OF MINING AND MECHANICAL ENGINEERS.

GENERAL MEETING,

Held in the Lecture Theatre of the Institute, Newcastle-upon-Tyne, December 10th, 1921.

Mr. C. C. LEACH, President, in the Chair.

ELECTION OF MEMBERS.

The following gentlemen were elected, having been previously nominated :—

Member—

Mr. George William Nasmith, Engineer, Norwood, Heaton Mersey, Manchester.

Associates—

Mr. Thomas Wood Green, Linesman and Assistant Surveyor, Findon House, Sacriston, Co. Durham.

Mr. Richard Eglenton Hall, Colliery Official, Englewood, The Parade, Chester-le-Street, Co. Durham.

Students—

Mr. Robert Brown, Mining Apprentice, 3, East View Terrace, High Heworth, Gateshead.

Mr. Henry Stott, Mining Student, Ravensworth Villa, Wrekenton, Gateshead.

THE LIMITATIONS OF COAL-CUTTING BY MACHINERY.

The President (Mr. C. C. Leach): Col. F. R. Simpson will open a discussion on the limitations of coal-cutting by machinery. The Council would like this question discussed as freely as possible; and although it is not usual to discuss a Presidential Address, Col. Simpson is willing to re-open the subject. As we wish the members to express their views with perfect freedom, anything which they may say which they would not like to appear in print will not be published.

Lt.-Col. F. R. Simpson (Blaydon-on-Tyne): When I delivered my valedictory Address as Retiring-President of your Institute, I gave some particulars of my experience of bord-and-pillar working by means of percussive coal-cutting machines, and promised to give detailed costs at a future date. The figures which I then submitted showed that in a seam 3 feet 9 inches thick, situated 3,200 yards from the shaft, the hewer was able to produce 2·18 tons per shift at a basis cost of 2s. 3·6d. when providing his own explosives. In the same district of the same seam the cost of coal got by means of percussive coal-cutters driven by air compressed by an in-bye electrically-driven compressor was 3s. 8·02d. per ton. The following are the detailed costs upon which my statement was based :—

I.—Average Cost of Coal-cutting over four Weekly Pays in November, 1918, in a Seam 3 Feet 9 Inches Thick. Days worked, 22; Tons produced, 1,650·6.

(*a*) Machine-mining.

Labour Charges.	Amount. £ s. d.	Basis cost per ton. s. d.	s. d.
Filling	83 2 0	1 0·08	
Cutting	47 11 8	0 6·94	
Cleaning	20 8 0	0 2·97	
Drilling	9 11 11	0 1·39	
Repairs to machines	2 11 6	0 0·38	
Compressor attendants	8 16 3	0 1·28	
Repairs to compressor	0 12 2	0 0·09	
Repairs to pipes	9 8 1	0 1·38	
	182 1 7	2 2·51	
Less Allowance for high cost of filling		0 3·00	
Net labour charges			1 11·51
Materials.			
Renewals of machines, repairs, and stores	17 16 5	0 2·59	
Extension of pipes	27 6 5	0 3·96	
Explosives	25 8 11	0 3·70	
			0 10·25
Capital Expended.			
Compressor, pipes, cables, cutters, etc.	28 7 8		0 4·07
Power.			
Electrical energy at 0·5d. per B.T.U.	42 12 1		0 6·19
Total charges for machine-mining	323 13 1		3 8·02

(*b*) Hand-hewing (24 Men).

Basis cost of all work performed by the hewer, who also provides explosives	103 18 6	2 3·60
Difference in favour of hand-hewing		1 4·42

It will be observed that the difference in labour cost is only 4·1d. in favour of the machine, but from this amount must first of all be deducted the cost of explosives, which is 3·7d., so that practically nothing remains to pay for materials, capital charges, and electrical energy, which together amount to approximately 1s. 4d.

The system of mining on which my figures were based was as follows:—

The compressor is capable of driving ten machines, and cutting was carried on in two shifts of 8 hours each, with an average of 4½ machines working; in other words, the compressor was running on half-load. The hours worked by coal-cutters and fillers were 8 from bank to bank.

Since the date of my Address special efforts have been made to reduce the costs. The present method is to do all cutting in one shift, and thus reduce the labour costs for compressing and so obtain better efficiency in the consumption of energy.

The hours of coal-cutters and fillers have been reduced from 8 (bank to bank) to 7 hours and 10 minutes, and there has been a reduction in the filling and cutting prices.

The thickness of the seam is now 3 feet 3 inches, as compared with a former 3 feet 9 inches. The hewing price has also been reduced, and the hewer produces 2·49 tons per shift, as compared with 2·18 tons previously. We have now a machine in each place, and flitting is practically abolished.

The following are the costs for two weeks' work in December, 1921 :—

II.—AVERAGE COST OF COAL-CUTTING OVER TWO WEEKLY PAYS ENDING DECEMBER 3RD, 1921, IN A SEAM 3 FEET 3 INCHES THICK. DAYS WORKED, 9; TONS PRODUCED, 721·15; CUTTING FROM 11 P.M. TO 6 A.M.; FILLING FROM 4 A.M. TO 4 P.M.

(*a*) MACHINE-MINING.

	Amount. £ s. d.	Basis cost per ton. s. d.		s. d.
LABOUR CHARGES.				
Filling	29 17 5	0 9·94		
Cutting	22 1 1	0 7·34		
Cleaning	7 17 10	0 2·63		
Drilling	5 2 9	0 1·71		
Repairs to machines	1 10 0	0 0·49		
Compressor attendant	1 19 2	0 0·65	2·36d.	
Repairs to compressor	0 0 0	0 0·00		
Repairs to pipes and extensions	3 13 4	0 1·22		
	72 1 7	1 11·98		1 11·98
MATERIALS.				
Renewals of machines, repairs, and stores	6 18 0	0 2·29		
Extension of pipes	24 0 0	0 7·99		
Explosives: Stomonal at 145s. per 100 pounds. No charge for shot-firing or detonators	11 14 11	0 3·91		
	42 12 11			1 2·19
CAPITAL EXPENDED.				
Compressor, pipes, cable, cutters, etc.	14 3 10			0 4·72
POWER.				
Electrical energy at 0·5d. per B.T.U.	6 14 1			0 2·23
Total cost for machine-cutting				3 9·12
(*b*) HAND-HEWING (16 MEN).				
Basis cost of all work performed by the hewer, who also provides explosives	16 0 4			2 1·29
Difference in favour of hand-hewing				1 7·83

It will be observed that I have charged power at 0·5d. per B.T.U., which is just about half the actual present cost, but the members can easily adjust this item to suit their own particular circumstances.

On the basis of the costs which I have given, I have made an attempt to arrive at the work which must be done by a coal-cutting machine in a shift of 7 hours and 10 minutes in order to compare equally with hand-hewing in this particular instance, and I am of opinion that this should not be less than 40 square yards, or, say, five places, which is just double the highest result that has been obtained in the district in question.

As an indication of the cause of these disappointing results, a chance record was taken in the district in question, and it was found that the actual hours of cutting by each machine was 2·7 out of a possible 5. This low working time is the key to the position. Flitting has been eliminated, and attention is now required to the setting of the machines, to keeping the cut at the correct horizon, and to the preparation of the face after the jud has fallen, so as to enable cutting to be started without delay.

In considering this question, I have always been sanguine of finding

a satisfactory solution, and in my opinion the only way to arrive at this is to have the actual experience of those who have made similar experiments.

I think it might justly be contended that my plant of ten machines is too small, and that a plant of a hundred machines might give better results. If this be a fair assumption, I shall be pleased to hear the results of those who have carried on coal-cutting on this larger scale.

I wish to make it quite clear that my figures relate only to percussive machines driven by compressed air as applied to bord-and-pillar workings.

We have installed electrically-driven machines of quite another type, and when they have been sufficiently long at work I shall be pleased to inform the members of my experience with them.

Mr. T. Y. Greener (Beamish): My first connexion with coal-cutting goes back a great number of years, probably to one of the first mechanical coal-cutters introduced into the County of Durham—some time about 1873-1874. I was at that time a young man serving my apprenticeship with the late Mr. Thomas Douglas, and he then introduced a compressed-air Gillett-&-Copley coal-cutter into the Yard Seam at Jobs Hill Colliery, which had a section of from 2 feet 10 inches to 3 feet in thickness, and was intersected by two stone bands. I was required to go into the pit with the coal-cutting shift each night, to keep a record of the number of yards cut during the shift, to note the length of each stoppage and the reason for such stoppage, and to report to Mr. Douglas. I cannot find any notes of the results obtained, but I have a very vivid recollection that whilst the coal-cutter was capable of undercutting to a depth of about 3 feet and, when all went well, of cutting a length of perhaps 50 yards during the shift, stoppages were very frequent by reason of accidents to various parts of the machine, so that the general results were not sufficiently satisfactory to warrant the extension of the system. The object of introducing the machine was to bring about a reduction in the cost of working; but it failed entirely to effect that object, not only on account of the inefficiency of the machine itself, but because the introduction of coal-cutting machinery involved a change in the method of working from bord-and-wall to longwall, and at that time the latter system was hardly known in the County of Durham; hence not only the workmen but the management were unaccustomed to the longwall system, and it was not a success.

I quite think that the coal-cutter might eventually have been successful if it had been given a sufficiently long trial, but the conditions of trade at that time were very much as they are at present. Prices were falling, working costs were high, complaints of dirty coal were frequent, and it was therefore decided to abandon the working of the Yard Seam. The coal-cutter was accordingly removed, and, so far as I know, never worked again. The Gillett-&-Copley was a disc machine, and its essential features were very much the same as the main features of similar machines to-day, although, of course, the details have been greatly improved since the time of which I am speaking.

My next connexion with coal-cutting was at a West Yorkshire colliery, in which compressed-air disc machines were very largely used. They were most efficient, the output derived from them was regular, and generally speaking this could be relied upon. I have not the statistics by me, but there is no doubt that machine-mining was a distinct success at that colliery. Its cost was not less than the cost of hewing by hand, but considerable advantage was derived from the fact that it was always

practicable to maintain a straight face and to produce a larger proportion of round coal than could be produced by hand, a most important consideration in West Yorkshire.

About 1900 I installed an electrically-driven Morgan-Gardner chain machine in the Clay Seam at Whitelea Colliery, Crook. The thickness of the seam did not exceed 2 feet, and was seldom more than 1 foot 10 inches. The coal-cutter was reliable, there was no difficulty in working it, and, so far as I remember, it used to undercut from 3½ to 4 feet. The amount of work it did was not unsatisfactory, but the introduction of the machine involved a change-over from single-stall working to longwall working, and it was found in practice that the cost of the additional stonework in the latter system of working more than balanced the advantages to be derived from the coal-cutter. Round coal was not a consideration: the seam was a coking seam pure and simple, and therefore the size of the coal was immaterial. The only advantage it was hoped to obtain from the coal-cutter was cheaper production; as it failed to accomplish that object, it was not worth while to continue the cutter in operation, and its use was therefore discontinued. This failure was not due to any fault in the machine itself, for if it had been used in connexion with a coal-conveyor it is quite likely the system would have been cheaper than manual labour. and it might have been in operation to-day.

During the last twelve months or so electrically-driven bar and chain machines have been installed in the Low Main and Hutton Seams at one or other of the South Moor and Holmside Pits. In the Low Main Seam at South Moor the bar machine is in operation in bord-and-pillar workings in a district underlying an area on which a large number of houses are built. It is therefore necessary to leave 65 per cent of the coal to support the surface. The cost of producing coal by hand under such conditions is prohibitive; the coal was hard, and the hewers were not producing more than about 1 ton per shift—in some cases not so much—hence heading-machines were introduced for the purpose of cheapening the cost of production, and they have effectually accomplished that object. The machines undercut to a depth of 6 feet, they flit from place to place upon their own skids, and as a rule each machine undercuts per shift five places having a width of 5 to 6 yards; indeed, on more than one occasion a machine has undercut seven places of the width referred to. Fillers are filling on the average 8·89 tons per shift, and occasionally fill 10 tons. It is most important, in order to secure the maximum amount of work from each machine, to reduce the amount of flitting to the minimum, and therefore so to arrange the filling that the machine is able to cut the places allotted to it in rotation, without having to flit backwards and forwards from place to place over the same ground. It is practicable to make such arrangement provided that due care is paid to the rotation in which the coals are filled from the places undercut by the machine. No difficulty has been experienced with the machines themselves, or with the conditions under which they are working. A bar machine is in operation in the Hutton Seam, which has a section of 2 feet 2 inches to 2 feet 4 inches, and the system of working is longwall. The production of round coal is not a material factor, the primary object of installing coal-cutters being to increase the output per person employed, and at the same time to reduce the cost of production. The machine has accomplished both those objects, and the output has gone up from a fraction over 2 tons per hewer per shift to 3½ tons per person employed at the machines. The latter figure is in my judgment capable

of further improvement, and I fully expect to see it increased very shortly.

With regard to the cost of machine coal as compared with hewing by hand, in the headings the saving is very considerable; in the longwall and headings combined the saving in cost as compared with hand-labour is about 6d. per ton. I am of opinion that there are advantages to be derived from the use of coal-cutters, quite apart from the difference in cost between machine and hand-labour: the hard work of coal-hewing is abolished, the maximum output can be obtained from a given area, and, having regard to the regularity with which the faces advance, the roof is not so difficult to uphold, and a saving in timber can be effected. Machine-mining has long since passed the experimental stage, the system has been very largely and successfully adopted in the thin, hard coal-seams of the Scottish coalfields, and I feel sure that it will come more largely into use in the English coalfields in the immediate future.

I have had some experience in the use of punching-machines driven by compressed air in the main winnings in the Busty Seam, to which a pit has recently been sunk at Craghead. The seam has a thickness of 3 feet, and the places in which the machines are working are 12 feet wide; they are being undercut to a depth of 5 feet, and each machine is cutting about three places per shift of seven hours. The winnings are let as "bargains" at a price per yard which includes the cost of making rolleyway height and of filling the coal undercut by the machines. It is impossible, therefore, to make a comparison of the cost of machine and hand-hewing, but I estimate that the present cost of producing coal in those places is 3s. 6d. per ton, and that the fillers would if they did nothing else fill about 8 tons per shift. It is intended to continue and extend the present system, because I feel satisfied that the coal is produced at a cheaper rate than it would be by hand-hewing, although I am not able from actual experience to make a comparative cost of the two systems.

Mr. H. F. Bulman (Acklington) wrote: The following notes are intended to give some idea of the progress made in mechanical coal-cutting since the publication of the Report of the Committee of this Institute on the subject in 1905. Being based on information received from some eighty colliery companies, using about 200 machines, that Report covered the ground fairly well at that time. It begins with the following statement:—

"Mechanical coal-cutting in this country is as yet only emerging from the experimental stage. This is indicated by the fact that most of the machines now in use have been started within the last 2 or 3 years."

The official figures for the years 1906 and 1920, as given below, show considerable progress during that period of fifteen years despite the many adverse conditions arising from the war:—

Year	Number of collieries where machines are at work.	Number of machines.	Worked by		Mineral obtained.* Tons.	Percentage of total output.
			Electricity.	Compressed air.		
1906	333	1,136	451	685	10,202,506	4·0
1920	760	5,073	2,154	2,919	30,746,274	12·8
Increase...	427	3,937	1,703	2,234	20,543,768	—

* Includes fireclay, ironstone, oilshale, and ganister.

The number of collieries where machines are in use has more than doubled. Of the 2,851 collieries at work last year, 760 (or about one-fourth) were using machines. The number of machines in use has grown from 1,136 to 5,073, a more than fourfold increase. The mineral got by them has gone up threefold, and the percentage of the total output in about the same proportion, namely, from 4 to 12·8.

In his recent Address as President, Col. Simpson refers to the low efficiency of compressed air, and the long-felt need of a percussive machine that can be driven by electricity. In this connexion attention may be called to the fact that electrically-driven chain and bar machines have now been adapted, by some changes in their construction, for use in narrow headings, and are being successfully employed for this purpose in preference to percussive machines.

Members interested in this development will find useful information about it in the little monthly magazine *Machine Mining* recently started by Messrs. Mavor & Coulson, Limited. Of course, where much "flitting" has to be done from heading to heading, the "punchers" have a distinct advantage in their smaller bulk and lighter weight, but they are wasteful consumers of compressed air.

The machines now available have been greatly improved in many ways when compared with those of fifteen years ago. It is the human element which is the variable factor and on which so much depends. Too much stress cannot be laid on the value of a well-trained crew of attendants for each machine. Their training should be something like that of a well-drilled gun-squad or of a rescue-brigade—each man practised in his own special duties and working in full conjunction with the others.

The results obtained will generally be in proportion to the experience, the keenness, and the perseverance of those who organize and those who control the work of the machines.

Compressed-air machines are still in a large majority, owing to the number of percussive machines, which are all driven by compressed air; but the electrically-driven machines, though fewer in number, account for considerably more than half the total mineral got. The figures for last year are 18,334,560 tons by electricity and 12,411,714 tons by compressed air.

In face of these figures it must be allowed that machine-mining has now passed the experimental stage, and calls for the careful consideration of all concerned in colliery management. The disappointing fact appears, however, that the steady rise year by year in the number of machines at work has not prevented a steady fall in the production per machine and per man employed. The tons cut per machine per year, which averaged 8,615 in 1902 and 8,496 in 1913 (the record year for total output of coal), fell last year to 6,060 tons. The heavy drop, too, in the production per man employed is well known. Technical progress has been more than counterbalanced by such mistaken legislation as the Minimum Wage Act and the Seven Hours' Bill. The hopes of those who thought that reduced hours of work would be compensated by increased use of machines have not been verified, but this is not the fault of the machines.

Of the 5,073 machines in use in 1920, 1,882 were of the percussive type, 1,254 were disc, 1,214 were chain, 694 were bar, and 29 were rotary heading machines. It is the chain machine that has been making most headway during the period under consideration. In 1906 only thirty-seven chain machines were in use. It is satisfactory to note that

this advance of the chain machine was foreshadowed in the Institute Report (page 17), as under :—

"Machines of this type adapted to longwall-cutting have been introduced lately, and are gaining ground. They have most of the advantages of the bar, with the additional one that the chain brings out the cuttings better than the bar. The chain, indeed, appears to be peculiarly well suited to this work, and, owing to its position at the end of the machine, the cuttings can be most easily dealt with."

Mr. J. J. Prest (Castle Eden) wrote : The experience of the Retiring-President on the subject of coal-cutting appears to me to have been very unfortunate.

Assuming the mining conditions to be satisfactory, the primary reason for the installation of coal-cutting plant to replace hand-labour is with the object of increasing materially the tons per man per shift employed, and perhaps our experience at Blackhall Colliery may be instructive in this respect.

In opening out the winnings in four of the seams, it was found in each case that the coal was so hard that first-class hewers could not obtain more than from 2 to 2½ tons per shift of seven hours, and, in consequence heading-machines of the "Hardy" and "Siskol" type were introduced, and are still operating over all the whole-coal workings.

During the two weeks ending November 5th, 1921 (10 days' work), 12,786 tons were obtained by machine-mining from three seams, 3 feet 1 inch, 3 feet 2 inches, and 4 feet 2 inches in thickness respectively, the balance of the output being obtained by hand-labour from pillar workings. The average tons per man per shift amounted to 4·21, after debiting the whole of the time of cutters, cleaners-out, drillers, and fillers, and the correct proportion of time occupied by fitters and pipemen, at an average cost per ton for these classes of labour of 4s. 6·24d. inclusive.

Our experience has been that if the seams are to be worked by bord-and-wall, and if good hewers cannot obtain more than 3 tons per man per shift in the whole coal, then there is undoubtedly a great advantage in the installation of suitable coal-cutters in the whole coal; but their success or otherwise depends very largely indeed upon the organization of the labour element.

At the present moment we have thirty heading-machines in operation, and the average output is about 47 tons per machine per day.

Mr. Sam Mavor (Glasgow) : I wish to submit that this question of machine-mining should be looked upon from a different point of view from that which most people have looked upon it in the past. The case which Col. Simpson has put before us is instructive in many ways, but it is not a test case of machine-mining. To begin with, I do not consider that the machine he used is a coal-cutter; it is a "percussive machine." The machine in this case has been applied in workings primarily developed and administered for hand-working. I think it is fair to state that what was done in this case was to put into the hands of the miner or pair of miners a mechanical tool to do their undercutting, and in the conditions under which the tool was applied its cost was a great deal more than its assistance was worth to the operator; that is broadly the reason for the non-success of the experiment. It is not an example of machine-mining; it is not even a sound basis for judging the merits of the type of machine concerned, although it indicates certain limitations of the type. Similarly, mechanical haulage might not be an

economic success if applied in roadways planned for hand- or pony-tramming; but under suitable conditions, and with the workings laid off with reference to the effective use of mechanical haulage, the expected economies should be realized.

The development in recent years of mechanical appliances for facilitating every branch of colliery work on the surface and underground is in advance of the development and practice of more economic methods of dealing with the primary problems of mining.

North of England mining engineers know best the conditions with which they have to deal, and they alone can determine the mining methods best suited to these conditions; but it is permissible to suggest that useful light might be thrown on their problems by investigating the best that has been done elsewhere under similar conditions. I venture to say that there is not sufficient coming and going between mining engineers in the different mining districts. It is remarkable that in this small country, with all its facilities for intercommunication, we should find different districts almost as watertight compartments in regard to methods and customs of mining, and this notwithstanding that we have an Institution of Mining Engineers with which are federated seven of the Mining Institutes of the kingdom. In the various districts local customs persist that may have been appropriate to the circumstances of their origin, but are incongruous and incompatible with modern methods.

If colliery-owners would encourage their officials to visit other districts, especially districts where the seams are similar to their own, the officials would certainly have an interesting and educative experience, and the coal-owners would profit handsomely by the more progressive methods that would be adopted. It is not for me to criticize your methods of mining your coal, but I know that mining people, who elsewhere are successfully mining thin seams under conditions similar to yours, would certainly not adopt the methods now practised in many of your seams.

A few years ago a paper was read by Mr. George Gibb, and it was discussed in this room.* I suggest that that paper is worth re-reading at this date. I do not know another paper of similar brevity that is so full of "meat." It is accompanied by a diagram that will repay close study. The method of mining advocated, or variants of it, for thin seams have since been adopted widely, and with very satisfactory results. Now that economic pressure is bringing machine-mining to the foreground, this suggestive paper will repay reconsideration in relation to thin-seam mining problems.

There has been a tendency to regard coal-cutters and conveyors as necessary evils, and to resort to them for seams which could not be worked profitably by hand. Where one or two coal-cutters are used in a hand-worked colliery, they are of secondary importance, and do not usually receive the attention necessary to secure the best result from the machines.

The time is ripe for a change of attitude to the whole subject of machine-mining; it should be considered seriously, not merely for seams that cannot be otherwise worked, but as a means of working to greater advantage many seams that by hand-working pay their way.

If, instead of putting in a coal-cutter or two into a hand-worked pit,

* "A Fresh Aspect of Intensive Mining Thin Seams," *Trans. Inst. M. E.*, 1917-1918, vol. liv., page 28.

the subject of machine-mining for a particular seam were carefully considered, and the development of the workings planned on the basis of the machines, and with special reference to realizing all the advantages of systematic machine-mining, very different results would be obtained. To introduce machines, either in bord-and-pillar or longwall work, without reorganization based on the machines is to court disappointment.

The first condition precedent to success is that the physical features of a seam should permit of the successful application of machines, but within wide limits the physical features are amenable to control. The other essentials to success are—a well-considered plan of development of the workings, a coal-cutter suited to the conditions and reliable in operation, machinemen skilled or teachable in the operating of the machine, and, finally, such organization of the operations in machine-worked sections as will ensure their prompt and regular performance and co-ordination.

Mr. Greener has told us how when a lad he was sent into the coal-face to report upon the performance of a machine. Any manager beginning machine-mining might with advantage select a smart young man and give him charge of the machine-operated section. There are many such youths of good education and some ambition who would be very glad to be closely associated with the inauguration of machine-mining. If such young men were selected and given responsibility, I am sure that the result would be satisfactory.

It is to be recognized that we have to deal not only with physical difficulties and inertia, but also with human inertia, and the latter is often the more difficult to overcome; until the necessity for overcoming it is faced, and steps taken to organize disciplined administration of machine-worked areas, you may struggle for a long time without success.

Mr. R. S. Tate (Trimdon): I think that Col. Simpson has rendered the coal-trade generally a service in stating publicly that he finds that percussive coal-cutting in headings is not profitable. I think that most of us who have had any lengthy experience with this type of work have, at one time or another, had similar experiences, but have not had the courage to make them public. Col. Simpson mentions a case where over 2 tons of coal per man per shift were got, but when you have a case where only one or two $8\frac{1}{2}$-cwt. tubs per shift are got by hand-labour, it is a different story altogether.

I think that a serious mistake was made in this coalfield at the very beginning—in fact, in the infancy of percussive coal-cutting; this was made when piece prices were fixed by the Coal Owners' Associations, as these, I think, were much too high at the commencement. The result is that although the men have not exactly got instructions, they have been practically told the amount of coal that they ought not to exceed when working with coal-cutters, and consequently they will not go beyond that figure. We have all had demonstrators at our collieries who have cut three, four, and five juds whilst our own men would cut two and no more, simply because they wanted the price arranged—and they got it. In a similar case where our men were getting one or two tubs per man we left off bord-and-pillar working and started longwall. We got on nicely on the longwall system, and put longwall machinery in. All went well, but unfortunately the undercutting turned very hard, and the longwall machines could not possibly cut more than 10 to 15 yards per shift owing to the difficult cutting breaking everything to pieces, so that it was necessary to abandon this method of working.

We have now got down to what I consider a satisfactory method of cutting with percussive heading-machines by advancing a straight open-face longwall so as to eliminate flitting. The cutting is very hard—black stone, which the longwall machine will not face (and for which most longwall-machine makers will not supply machinery). In that longwall face the best men are cutting 30 square yards per shift in a seam 2 feet 4 inches high, and the fillers are each filling 8 tons. I was both surprised and pleased when I got the results. What I am aiming at is that we should not condemn either heading or longwall methods *en bloc*, but must consider every case on its merits. Where the conditions are such as to allow cutting with longwall machinery, it is, of course, absurd to continue with a heading-machine, unless you have a specific reason for doing so.

Mr. FRED. L. BOOTH (Ashington): The question as to whether or not it is more advantageous to work a seam or district of a seam by means of coal-cutters can only be answered satisfactorily by a practical test. It might be possible for a man with a large experience of coal-cutting under a variety of conditions to see a similarity between the conditions of a seam into which it is proposed to introduce coal-cutters and some other seam with which he has had experience, and then to form some idea as to the result, but such occasions would be rare. We know that coal-cutting does pay, given suitable conditions; but it must not be forgotten that some of those conditions are also favourable to hand-hewing.

After the practical test has been made, and it has to all appearance turned out satisfactorily, it is necessary to search very closely to see whether the experiment has not been benefited in some form at the expense of another part of the pit. A case in point would be extra supervision. The interest taken in an experiment by the officials tends to smooth away difficulties, but these officials cannot devote their time to one part of the pit indefinitely.

Then, again, for an experiment of this nature it is natural to select the best workmen, and the general average of the rest of the pit may be lowered thereby.

Again, the output per man in the district may show an increase under the conditions, but it does not follow—in fact, in my experience it very seldom follows—that the output from the district increases where coal-cutting is introduced. In that case allowance must be made for the cost of upkeep and working the extra pit-room required to make up the output of the pit.

I know it has often been stated at these meetings that one advantage from the use of coal-cutters is the increased output from a given area, but my experience, as already stated, is entirely the reverse, except under special circumstances—perhaps where the coal-cutters are used in conjunction with face-conveyors, for example, or on a long face with three or four coal-cutters following each other across, but this is not a condition possible in many mines.

I mention the above points to emphasize the fact that results obtained from coal-cutting on a small scale cannot be accepted as a guide as to what would be the result if the whole seam or pit were so worked.

I do not wish to discourage the use of coal-cutters—far from it; and the fact that 60 per cent. of the output at the colliery with which I am connected, or nearly 3,000 tons per day, is got by coal-cutting, and that there has been a gradual increase in the amount so got during the last

twenty years, speaks for itself; but it is the 40 per cent. that is not got by coal-cutting that deserves attention. Generally speaking, this 40 per cent. is not so got because coal-cutting has proved unsuccessful as compared with hand-holing in the same districts.

The actual saving by coal-cutting, taking an average throughout the colliery, is comparatively small, and it is necessary to watch carefully those instances on the border-line. As an example, I know of a seam 2 feet 9 inches thick where coal-cutters were gradually introduced until 80 per cent of the entire output was got by their help, and now the percentage is back to 30, the coal-cutters having been taken out of those places where we were satisfied that they were not paying. At the same time, in the remaining 30 per cent. of the same seam coal-cutting is quite a success. Amongst the drawbacks I include ramble difficulties and working over old goafs. Sometimes also a change of type of machine may be necessary to ensure success.

In the foregoing example it is a common practice to change from disc to chain, or *vice versa*, as circumstances demand, and on one occasion the only successful appliance was a bar machine cutting in tender coal on the top of the seam.

In a discussion such as this figures as to costs would be of little value, as the time is too short to discuss all the conditions and circumstances relating to such costs, and a thorough knowledge of the conditions in any particular case is essential if they are to be of any value.

About two years ago a statement was asked for by the Coal Controller as to costs and output from coal-cutters under various conditions, but the answers to the tabulated list of questions did not give sufficient information for the figures to be of any practical value. It might be thought advisable to bring those figures up to date and get fuller information of the conditions under which the coal-cutters were working, and with costs given per square yard instead of per ton, for the purpose of this Institute.

With regard to coal-cutting in narrow places, the usual method is by percussive machines driven by compressed air. The cost per square yard is from two to two-and-a-half times the cost of cutting in the longwall, but in order to gain the advantage of longwall cutting costs a change in the method of working the seam from bord-and-pillar to longwall is necessary, with generally an increase in costs in stonework, which more than counterbalances the saving in cutting.

I have recently tried electric heading-machines of the bar and Sullivan type, and while the actual cutting of the places occupied only a few minutes, the time taken to flit to the next place more than counterbalanced the saving in cutting time as compared with the percussive machine. This was entirely due to the timbering difficulty on the roadways and turns, but I can quite understand these machines being successful in a seam where the roof is good and little timber is required on the roadways.

At present I am experimenting with an electric heading-machine made by the Hardy Patent Pick Company, Limited. It is very similar to the percussive machine, but is fitted with an electric $1\frac{1}{2}$-horsepower motor instead of an air-cylinder. The cutting action is the same as in the bar machine, the machine is fixed to an upright stand, and it is slewed round in the arc of a circle as in the percussive machines. The motor in its cradle is moved forward about 2 inches at the commencement of each cut. The cutting-bit is fixed on the end of a rod, and the cutting-edges are, of course, set radially.

This machine is at present cutting in a medium fireclay, and the best result so far has been two places cut 4 feet deep and 12 feet wide in a 7-hour shift (bank to bank). I think that there are possibilities in this machine if suitable cutting-tools can be designed. In soft cutting where it has been tried the results are very satisfactory.

Mr. W. H. JOHNSON (Durham): Mr. Mavor has already fairly well covered the points on which I had intended touching, but I cannot emphasize too strongly the importance of his remarks as to the proper preparation of the places, and especially of the roadways, when machine-mining is being started in bord-and-pillar workings. My remarks apply to the use of electrically-driven bar machines as distinct from punching-machines. The time taken to cut each place is a matter of only from 10 to 20 minutes, this depending upon the width of the place and the nature of the holing material, so that it is to the necessity of economizing time when flitting that I desire to direct your attention.

It is essential that the roadways should be kept clear of obstructions, such as bad joints in the rails, irregular packs, and projecting props. With regard to the stripping of the coal in the working-places, it is necessary, in order to obtain the best results, that the work should be so organized that the places are stripped and are available for cutting in sequence. For instance, if one has a sheaf of bords, say, six in number, the machine should be able to cut those places in rotation—that is, Nos. 1, 2, 3, 4, 5, and 6—and during the next shift it should cut them in reverse order—Nos. 6, 5, 4, 3, 2, and 1.

It is surprising how often one finds that the places have to be cut out of turn—say Nos. 1, 4, 5, 2, 3, and 6—owing to their not having been stripped, or to their having a ripping shot down in them when the machine is ready to cut them. This irregularity means a considerable increase in the time occupied in flitting, and consequently spells inefficiency.

I could quote cases where the results have been improved by exactly 100 per cent. within a fortnight entirely by improved organization. I do not wish to give the impression that I consider the bar heading-machine to be infallible. We know only too well that it is not. There are certain conditions to be found underground to which, in its present form, it is not suited, and there, no doubt, the punching-machine can hold its own—for instance, in the thin seams of the Bishop Auckland district, where the coal is worked on the bord-and-pillar system, with bottom canches.

With reference to Mr. Greener's remarks on the very creditable results obtained from the electrically-driven bar heading-machines at the collieries with which he is associated, I see no reason why the same results should not be obtained at any other colliery where the natural conditions are reasonably good.

Mr. Greener's success is, in a very large measure, attributable to the efficient organization and to the whole-hearted co-operation of the entire official staff.

Mr. RICHARD SUMMERBELL (Preston Colliery): In accordance with the wish expressed by Col. Simpson in his Presidential Address, we at Preston Colliery have prepared a statement covering a period of ten months in regard to machine-mining in bord-and-pillar workings, with compressed air as the motive power.

In February, 1919, it was decided to work the Top Busty Seam with

the "Hardiax" machine and the Hardy "Simplex" hammer-drill. The section of the seam is as follows:—

	Feet.	Inches.	
Top coal	0	11	
Band	0	2	
Coal	1	4	(with thin partings of stone).
Band	0	6	
Bottom coal	1	5	
Total height ..	4	4	(with a good post roof and seggar bottom).

I am sorry to say that I cannot give any comparison of the cost of working this seam by hand-labour, as it was driven only 6 yards at 6 feet wide from the shaft-walling during sinking operations. The sinkers complained that it was so bad to work, owing to its being interlaced with stone bands, that they could not get more than 10 cwt. per shift.

On March 10th, 1919, we were able to place four fillers in each of the three shifts, or a total of twelve fillers, thus finding work for two cutting-machines during three shifts per day, three drillers, and one pipeman, making a total of twenty-eight men employed. The number of tons raised during the first week was 952 for 152 shifts worked, which averages 6·2 tons per shift per man employed.

We continued to increase the number of men as the seam opened out, and on June 19th the filling price was fixed at 6½d. per ton, plus ½d. per inch per ton below 4 feet high, this rate to apply when places are under-cut, all cuttings cleaned out and cast back, and all holes drilled. The bands in the seam were paid for at ¼d. per ton per inch of thickness, so that the total price for filling coal with 8 inches of band was 6½d., plus 2d., or a basis rate of 8½d. per ton. The cutting and cleaning-out agreement was fixed at 8d. per ton, this amount including payment to both cutter and cleaner-out. The drilling price was fixed at 1½d. per ton. The total price, therefore, for filling, cutting and cleaning-out, and drilling was 1s. 6d. per ton.

On July 14th, 1919, the Seven Hours' Act came into force, which proved to be a serious handicap to mechanical coal-cutting. In order to illustrate this, the following table has been prepared to show the work done in cutting, filling, and drilling from March 10th to July 12th, when the Eight Hours' Act was in operation during the eighteen weeks in question:—

Labour.	Total tons.	Shifts worked.	Tons per shift.	Cost per ton. s	d.		
Fillers ...	29,069	2,116	13·73	2	3·1	s	d.
Cutters ...	30,317	2,257	13·47	1	5·0	4	0·1
Drillers ...	30,317	415	73·00	0	4·0		
Putters ...	—	—	—	0	5·8		

The total number of shifts worked during the above period was 5,314, which includes fillers, cutters, scrapers, drillers, pipemen, machine-fitter, and pick- and drill-sharperens. The average output per man per shift worked is 5·7 tons.

The following table is for a period of twenty-three weeks worked when the Seven Hours' Act was in force:—

Labour.	Total tons.	Shifts worked.	Tons per shift.	Cost per ton. s.	d.		
Fillers ...	51,776	5,229	9·91	2	8·0	s.	d.
Cutters ...	54,971	5,638	9·75	2	1·1	5	1·9
Drillers ...	54,971	947	58·00	0	4·8		
Putters ...	—	—	—	0	8·5		

The total number of shifts worked during this period was 12,700, which includes the same classes of workmen as during the first period, and the average output per man per shift is 4·4 tons, or a decrease of 1·3 tons.

In placing before you these two tables, it is not quite correct to say that the conditions were similar during the two periods, because in the first while the fillers were working on contract no "laid-out" scale had been fixed, and the men were not very particular about cleaning their coals; but during the second period a "laid-out" scale was in operation. With this exception, however, the two tables were worked out under similar conditions, so that the large difference in output is due mostly to the Seven Hours' Act, or as it is commonly called the "Sankey Award." This reduction of hours was understood by the general public to be a reduction of the working hours from eight to seven, but instead of this in most cases it was a reduction from $6\frac{1}{2}$ to $5\frac{1}{2}$ hours' actual work, which accounts for the very large decrease shown above.

This system of coal-getting is penalized—that is to say, the men working with and after the machines have to be paid 1s. 1d. per shift more than the ordinary coal-hewer, although both classes work the same number of hours.

The fact now seems to be overlooked that the reduction in the hours worked is very largely the cause of the severe cuts in wages, and the sooner it is realized that the Eight Hours' Act should be restored the sooner will the collieries work economically and be better able to pay higher wages.

In reference to the general working of this system of coal-getting, it is absolutely essential that the management should have the whole-hearted support of the official staff, and as far as possible that of the workmen as well.

The following is a list of particulars that the officials' reports contain each day:—

Number of fillers at work.	At each flat.
,, ,, cutters ,,	
,, ,, drillers ,,	
Coals filled per set of fillers.	
Number of places undercut by each machine.	
,, ,, ,, standing undercut.	
,, ,, ,, to undercut.	
,, ,, ,, half filled off.	
,, ,, ,, ready blown down.	
,, of holes drilled during shift.	
,, ,, ,, to be drilled.	

The officials have also to report the distance of the air-pipes from the different faces.

The type of air-compressor installed during this period was a two-stage horizontal steam-driven machine made by Walker Brothers (Wigan), Limited, giving an output of 4,000 cubic feet of free air per minute at a pressure of 80 pounds per square inch. During this period we had twenty cutting-machines, fifteen drilling-machines, and eight 4-inch double-acting Evans pumps working per shift, in addition to other machines used for sundry purposes and working on the surface.

The air-tubes used for conveying the air into and around the mine are as follows:—A 9-inch main from the compressor to the large receiver on the surface, a 9-inch main from the receiver on the surface into a receiver at the Low Main Seam, and three 6-inch branches of air-tubes from the above receiver into the main districts and down the shaft to the

Top Busty Seam into another receiver. From this receiver two 6-inch mains are carried as near as it is practicably possible to have them into the main districts. From these mains into the different flats they are reduced to 3 inches, and a further reduction is made in the distributing-pipes, which are 2 inches in diameter. From the receiver at the different seams the pipes used are all of one design, fitted with what is called the " Ruglen " loose flange, with spigot and fawcett joints, which make a most perfect fit.

It will be observed from the number of machines working that the consumption of air is practically equal to the output, but as doubtless you are aware the machines are only working intermittently.

The cost of the air-pipes during the year, including tee-pieces, bends, valves, etc., was 1·8d. per ton. The cost of spare parts for the machines is a very varying quantity, and depends very much on the type of men working the machines. We find that men possessed with some mechanical skill make the most efficient cutters.

During the current year we drove a stone drift from the Low Main Seam to the Bensham Seam a distance of 220 yards, which was practically all undercut, and the one machine started and finished the drift without once being sent out for repairs. The cost over the period for spare parts was 2·83d. per ton. The cost for motive power, which includes cost of coal for boilers, firemen's wages, lubrication, etc., which items were all very high during this period, works out at 10·5d. per ton.

The total tons cut during the last six months of 1919 averaged 740 per day; three stone drifts were driven, and the whole of the working-places were drained of water by air-pumps, the entire work being done by the output of air from the Walker compressor.

Taking all these circumstances into consideration, you will not be surprised to hear that the whole staff of officials and workmen of the colliery realize that mechanical coal-cutting has come to stay. All the coals produced at the colliery are now got by this method.

Mr. Mark Ford (Washington): I wish that Mr. Tate had amplified his remarks a little, because he has had experience of the system which his father practised in the Low Main Seam at East Hetton Colliery, where the hewers kirved in the fireclay below the seam and other workmen filled the coal. The cost for kirving varied from 6d. to 1s. per square yard, which compares very favourably with the price paid to labour for cutting in the County of Durham to-day with a 30-horsepower machine. A smaller quantity of explosives was used, as the coal had a greater distance to fall. This method was carried on successfully for a long time, and its adoption enabled the coal to be produced with a minimum of small. This factor of a smaller quantity of small coal produced has not been mentioned to-day, but something might be said on that point.

With regard to coal-cutters in general, it is remarkable that there has been so little done towards improvement of manufacture in the Newcastle Coalfield.

Col. Simpson has put forward his figures as a basis, but how has he found his basis figures for capital and power costs? I think he will find that in manual labour he should add to his present-day gross cost about 15 per cent., this being the equivalent for house-rent and for the coal allowed to the workmen. In machine-mining it would not be necessary to add this 15 per cent., because a great deal of the cost would be due to the machine and not to labour. I would suggest that Col. Simpson should also add to his list the cost of insurance and compensation, which will augment the labour cost.

Section of Seam.

	Feet.	Inches.	
Coal ...	1	9	Machines cut the band out. Very little timber required; no re-setting of timber to accommodate the machines.
Band ...	0	4	
Coal ...	0	10	
Total ...	2	11	

System of Working.

Bord-and-wall; 20 per cent. of seam extracted in the whole working, the remaining 80 per cent. being extracted as a longwall-face in the broken working.

Type of Coal-cutting Machine.

"Siskol" 90 type, worked by compressed air at a pressure of 70 pounds per square inch at the compressor.

Details.	Hewing (whole work).	Machine-mining (whole work).	Hewing (broken work).
Average square yards cut per machine shift	—	13·23	—
Average tons undercut per machine shift	—	11·10	—
Machinemen employed per machine shift	—	1 man and 1 lad (16 years old)	—
Period taken ...	5 weeks	3 months.	3 months.
Tons produced ...	272	Tons. Cwt. 1,415 4	Tons. Cwt. 2,024 1
Shifts worked by coal-getters ...	187	Fillers ... ... 333; Machinemen ... 256½ = 589½	683
Output per shift per coal-getter, in tons	1·45	Filler ... ... 4·25; Filler-machineman 2·40	2·96
Basis earnings per shift	2s. 11·73d.	Filler ... 7s. 0·23d.; Machineman 5s. 3·78d. = 6s. 3·34d.	5s. 7·63d.
Basis earnings per shift, plus 121·19 per cent.* ...	6s. 7·03d.	13s. 10·65d.	12s. 5·59d.
Add minimum wage per shift	1s. 11·80d.	Nil.	1·63d.
Toal earnings per shift	8s. 6·83d.	13s. 10·65d.	12s. 7·22d.
Basis cost per ton ...	2s. 0·57d.	Fillers ... 1s. 7·82d.; Machinemen 11·54d. = 2s. 7·36d.	1s. 10·82d.
Basis cost, plus 121·19 per cent.*	4s. 6·35d.	5s. 9·37d.	4s. 2·48d.
Add cost per ton for minimum wage ...	1s. 4·36d.	Nil.	0·55d.
Total wages cost per ton ...	5s. 10·71d.	5s. 9·37d.	4s. 3·03d.
To which has to be added, for machine-mining only, a charge of about 1s. 6d per ton for cost of compressed air, machine stores and repairs, and interest on capital	—	1s. 6·00d.	—
Total cost per ton ...	5s. 10·71d.	7s. 3·37d.	4s. 3·03d.

* The percentage addition of 121·19 was the current rate when these figures where taken out.

Most of us have had the experience of Mr. Greener, and were compelled to put in machines when the hewers' output dropped to 1 ton per shift. One mining engineer with a large experience states that if you can get 2½ tons per shift by manual labour, do not use machines; while another says put in machines if you cannot get more than 3 tons. It is difficult, however, to be dogmatic on methods of working, and the only reliable proof is the result of experience, as no rule can be laid down to cover every problem.

Mr. E. W. Milburn (Woodhorn Colliery): When I first saw Col. Simpson's Address and his remarks respecting his experiences with percussive coal-cutting machines, I was struck with the similarity of the results achieved to those obtained in a district of a seam which I am at present working. Percussive coal-cutting machines have been employed in this district for over ten years to drive headings 9 feet and 18 feet wide respectively, forming pillars which are afterwards removed in a retreating longwall-face by coal-hewers. Some few months ago the experiment was tried of driving the headings by hand-hewing. The results obtained are given in the table opposite. It should be understood that the hewers driving headings were working side by side with the coal-cutting machines, which also were driving headings, and that the hewers taking out the pillars formed during the "whole" working were only 60 yards behind the "whole" face, so that the conditions of the seam for the three different classes of work were as similar as was possible.

Mr. Jackson Swindle (Swalwell): We have a little seam, about 1 foot 9 inches thick, which we found we could not operate profitably when worked by hand-labour. Our output was 18 cwt. per man and the cost about 8s. per ton with the county percentage at 60. If the cost of rent and coals is added, it means at least another shilling per ton, for nearly every workman is married nowadays. We installed an in-bye compressor as an experiment, the capital cost of which came to about £1,000, and started it before the Sankey Award came into operation, which was when I took these figures out. We found then that we got 3 tons of coal per man employed by the machines out of a 21-inch seam. The total cost of working by the machine was 5s. 6d., plus 6d. for power, 3d. for repairs, and 6d. for depreciation, or a total of 6s. 9d. A similar output for manual labour would have cost 14s., including 107½ per cent. and 3s. war wage, so that there was a saving of 7s. 3d. per ton. I do not say that percussive machines are the most economical, but where bord-and-pillar working has to be adopted they are the most suitable; where the longwall method can be worked, coal-cutting machines are still better.

Mr. William Severs (Beamish): I think that most of the discussion so far bears out Col. Simpson's contention. I have had machines which were suitable under certain conditions, but when the seam is only 20 inches high it is more difficult to employ them, especially if there is a bad roof throughout the seam. At one place, with 24 inches of coal at the bottom and 24 inches at the top and a band of about 5 inches in the middle, machine-mining worked advantageously; while in other places, with coal from 24 to 30 inches thick and a bad roof, the results were poor. I was not satisfied with our own men's working, so I got some workmen from neighbouring collieries, who told me that they could cut three or four places in a shift, but when they came they cut no more than my own men. It is all very well to blame the organization in the pit when the machines are not going, and to say that when flitting them

all the timber should be out of the way; but it is sometimes impossible to get all the timber out of the way. With regard to the machine moving along the skids easily, it sometimes skids on the way first on one side and then on the other, knocking out props, and when it comes to be turned the same difficulties arise, unless the turning-places are stuffed with wood between the crossings and the points. "Glutting" a turn takes some time, and then there are other items to take into consideration. Mr. Summerbell has obtained some remarkable results, but doubtless he has also some remarkable seams. I cannot get such good results at the collieries under my charge.

I have now a chain type of machine at work in a 30-inch seam. At the beginning this machine was supposed to cut itself out on the fast as well as on the loose side. We had an expert to work it, but he was never able during the whole month he was at the colliery to jib the machine out as he said he would. Eventually I was obliged to make a stall to cut into for the machine. We have a conveyor, but could not get the coals off in one shift with a $4\frac{1}{2}$-foot cut, so we came to the conclusion that the best way would be to reduce the jib, and with a $3\frac{1}{2}$-foot cut we cut right across the whole of the face, turned the machine, and oiled and picked it in seven hours from bank to bank. That method has been pursued for about nine months, except for one day when we had a breakdown. We get from 80 to 100 tons of coal off that face every day with seven or eight fillers. There is no doubt that in this case the results are very good, and when the output is averaged over the whole of the men employed (that is, fillers, cutters, and pullers-up) it works out at 5·4 tons per man. We have two instances of machine-mining in the same seam: one is a comparative failure like that of Col. Simpson's, but the other is a great success. Everything depends upon the circumstances, and not so much on the organization as has been claimed by some of the speakers to-day.

The discussion was adjourned.

MEAN MAGNETIC DECLINATION (WEST) FOR EACH TWO-HOUR INTERVAL FROM JANUARY 1st TO JANUARY 28th, 1922, AS RECORDED AT KEW OBSERVATORY, RICHMOND.

Day of Week.	Day of Month.	Magnetic character.	Intervals in hours (Greenwich mean time). 0h. to 2h.	2h. to 4h.	4h. to 6h.	6h. to 8h.	8h. to 10h.	10h. to 12h.	12h. to 14h.	14h. to 16h.	16h. to 18h.	18h. to 20h.	20h. to 22h.	22h. to 24h.	Mean for day.
			14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+	14°+
	Jan.														
Sun. ..	1	0	13′5	13′5	14′0	14′0	13′5	15′0	15′5	15′5	14′0	14′0	13′5	13′0	14′0
Mon. ..	2	1	14·0	14·5	14·5	14·0	13·0	13·5	14.5	15·0	14·5	13·0	11·0	10·5	13·5
Tues. ..	3	0	13·0	14·0	14·5	13·5	12·5	13·5	15·0	15·0	14·0	13·5	13·5	13·0	14·0
Wed. ..	4	0	12·5	14·0	14·5	14·0	13·5	15·5	16·0	15·5	14·5	14·5	14·0	12·5	14·5
Thur. ..	5	0	12·5	13·5	14 5	14·0	13·5	15·5	16·5	15·0	14·5	15·0	14·0	13·0	14·5
Fri. ..	6	0	13·5	13·5	14·0	14·0	13·5	16·0	17·0	15·5	17·0	15·5	13·0	12·0	14·5
Sat. ..	7	1	10·5	11·5	13·0	14·5	16·0	15·5	16·0	14.5	13·5	13·5	13·0	13·0	13·5
Sun. ..	8	2	14·0	14·5	14·5	14·5	14·0	15·0	18·0	18·0	12·5*	14·0*	8·0*	11·5*	14·0
Mon. ..	9	2	14·5*	12·5*	17·5*	16·5*	15·0	16·0	17·0	14 5	11·5	10·0	11·0	12·0	14·0
Tues. ..	10	1	13·5	15·0	16·0	16·0	15·5	16·0	15·5	14·5	12·5	12·0	11·0	11·5	14·0
Wed. ..	11	1	14·5	13·5	16·0	16·0	14·5	16·0	15·0	13·5	12·5	12·5	12·5	13 5	14·0
Thur. ..	12	1	15·0	14·5	14·0	13·5	13·5	15·0	16·0	14·5	13·5	12·0	13·0	13·0	14·0
Fri. ..	13	0	12·5	14·5	14·5	13·5	13·0	14·5	15·0	14·0	14·0	14·0	13 0	13·0	14·0
Sat. ..	14	0	14·0	14·0	14·0	13·5	13·0	14·0	15·5	15·0	13 5	11·5	12·0	12·5	13·5
Sun. ..	15	0	13·5	14·5	14·5	13·0	12·0	13·5	15·5	15·0	14·0	13·5	13·0	12 5	13·5
Mon. ..	16	2	13·5	14·5	14·5	14·0	12·5	14·5	17·5	16·5*	16·5*	13·5*	8·5*	5·0*	13·5
Tues. ..	17	2	6·5*	10·0*	13·5*	14·0	13·5	13·5	15·0	16·5	15·5	12·5	13·0	12·5	13·0
Wed. ..	18	1	12·0	13·5	13·0	13·0	13·0	14·5	15·5	15·0	14·5	10·0	10·5	11·0	13·0
Thur. ..	19	1	12·5	12·5	13·0	13·0	13·0	14·0	15·0	14·5	14·5	12·0	10·0	12·5	13·0
Fri. ..	20	1	13·0	13·0	12·5	13·0	13·5	15·5	16·5	14·5	12·5	13·0	12·5	12·5	13·5
Sat. ..	21	0	13·0	13·0	13·0	12·5	13·0	15·0	16·0	14·5	13·5	13·0	12·5	12·5	13·5
Sun. ..	22	0	13·0	13·0	13·0	12·5	12·5	15·0	16·5	15·0	14·0	13·5	13·0	12·5	13·5
Mon. ..	23	0	12·5	12·5	13·0	12·5	12·0	15 0	16·0	13·5	14·0	14·5	14·5	12·0	13·5
Tues. ..	24	2	9·5	7·5	9·0	12·5	14·0	16·5	19·5	21·0*	10·0*	14·0*	12·5	11·0	13·0
Wed. ..	25	2	9·0*	10·0*	14·0*	19·0*	16·5	16·0	15·0	13·5	9·5	10·0	12·5	11·5	13·0
Thur. ..	26	1	9·5	11·0	14·0	13·5	15·5	17·0	16·5	14·0	13·0	13·0	11·0	12·5	13·5
Fri. ..	27	1	12·0	11·5	13·0	13·0	13·0	14·5	15·5	13·5	12·5	12·5	12·0	12·0	13.0
Sat. ..	28	0	13·0	13·5	13·5	12·5	12·0	13·5	14·5	13·5	12·5	12·0	12·0	10·5	13·0

Diurnal Inequality (i.e., departure from mean value for day).

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January, 1921	−0′9	−0′5	−0′6	−0′3	−0′5	−0′6	−0′6	−0′.5	+0′1	+1′1	+1′9	+2′9
December, 1921	−0·6	+0·1	0·0	+0·4	+0·2	+0·1	+0·1	−0·3	−0·4	0·0	+1·2	+1·9
December, 1920	−1·0	−0·4	0.0	−0·1	0·0	0·0	0·0	0·0	+0·4	+1·3	+2·0	+2 4

	13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.
January, 1921	+3′0	+2′3	+1′5	+1′1	+0′8	−0′1	−1′1	−1′7	−1′8	−2′1	−2′0	−1′4
December, 1921	+2·4	+2·1	+1·4	+0·9	+0·5	−0·3	−1·1	−1·2	−1·5	−2·1	−2·2	−1·5
December, 1920	+2·3	+1·8	+1·2	+0·8	+0·3	−0·2	−1·0	−1·2	−1·7	−2·7	−2·2	−1·8

* Large disturbances during this interval.

Mean Value for Month.

January, 1921.	December, 1921.	December, 1920.
14° 25′·8.	14° 14′·6.	14° 26′·3.

REMARKS.

The day is counted from 0h. (midnight) to 24h. (midnight), G.M.T.

Character "0" means a day wholly free from any but small disturbances.

" "1" " " part or all of which is moderately or considerably disturbed.

" "2" " " part or all of which is highly disturbed.

The normal value for an hour is the mean declination for that hour in the month, derived from quiet days only, or from all days excluding those of character "2." On a day of character "0" declination at any hour will usually be within about 3′ of the normal. On a day of character "1" the departure from the normal will usually not exceed 5′, but it may occasionally be as much as 10′, or even more. On a day of character "2" the departure from the normal will seldom exceed 20′, but departures of 30′, or even on extreme occasions of 1° or more, may occur.

The above values were obtained from measurements made after "smoothing" the curves.

THE INSTITUTION OF MINING ENGINEERS.

THIRTY-SECOND ANNUAL GENERAL MEETING,

HELD IN THE COUNCIL CHAMBER, TOWN HALL, STOKE-ON-TRENT, SEPTEMBER 14TH, 1921.

COL. W. C. BLACKETT, C.B.E., RETIRING-PRESIDENT, IN THE CHAIR.

RECEPTION BY THE MAYOR OF STOKE-ON-TRENT.

The MAYOR OF STOKE-ON-TRENT (Alderman Sampson-Walker): On behalf of the borough of Stoke-on-Trent, and perhaps the outside areas also would permit me to speak on their behalf, it gives me very great pleasure indeed to welcome your Institution here for the first time for a long period of years to hold your annual gathering and take part in your annual discussions. I understand that you have not visited the district since 1906, partly owing to the incidence of the war, which prevented you from making your customary arrangements; but I am sure that, speaking on behalf of the general public, we are delighted to welcome you; and also I assure you that not only are we all most interested in your deliberations—which deal, of course, with matters very essential to everyone in this country at the present moment—but we welcome you also as individual gentlemen into this district. I have been reminded by Mr. Allott, and I have heard it mentioned before, that this district is well known as being a most difficult one from your point of view—that is, for the working of the seams, etc.—and so we have some comprehension, at any rate, of some of the difficulties which you gentlemen have to meet and overcome in the carrying out of your duties as engineers in the mining industry. The fact that I have been living in this district the whole of my life, and that my business has brought me into touch with a number of the members of your Institution, has led me to believe that the work you do is of a most responsible and hazardous character, and that the gentlemen who have it in charge are in every way fitted—I say this in no flattering sense—to carry that work through successfully. We, along with the rest of the United Kingdom, are looking to you of the coal industry to bring, as doubtless you are doing and will continue to do, to the consideration of the great problems with which you and we are faced such experience, knowledge, and wisdom as we know you possess; so that we are looking forward, at any rate, to some relief in the matters which bear so heavily upon manufactures in this country. I am not saying that in any contentious spirit, nor even shall I say in the way of advice or request; but rather we look to you at this juncture, with the trade of the country in so hazardous a state, to do what you can to relieve the tremendous cost of manufacture that is bearing so heavily upon the home country. You must excuse me upon that point, because it is the point that is uppermost in our minds, as probably it is in yours also; and with these few words I would like to say that we wish you a very happy stay in this district, and that your deliberations will be of benefit to yourselves, to

your industry, and to the country at large. Mr. President, on behalf of the borough and the population of this district, I give you the heartiest welcome to our midst.

The Retiring-President (Col. W. C. Blackett, C.B.E.): Mr. Mayor, on behalf of our Institution, and on behalf of all the members who are here to-day, I beg to return to you our most grateful thanks for the way in which you have received us. We are grateful to you for the personal side of your welcome—for your welcome as man to man—and we are grateful to you for your welcome in your official position. You have extended to us the hospitality of these buildings, which we greatly admire, and for that we wish to convey specially to you and to those you represent our thanks. We are also grateful to you for the sympathy that you have expressed to us in our capacity as miners. We have been going through very hard times lately for very many reasons, and it is refreshing indeed to get anyone to stand up and say that they sympathize with us, and are wishful to see us through all our troubles. We especially represent the safety and welfare of our mines; and while we wish to work the mines as economically and as safely as we possibly can, you may rest assured that if coal can be delivered to you more cheaply, it will be done by the kind of men that you see around you here to-day. I do not think I can express any further views at the moment on the coal industry, but I wish to preserve the note of gratitude we have for your official and personal welcome to-day.

THIRTY-SECOND ANNUAL REPORT OF THE COUNCIL, YEAR 1920-1921.

In submitting the Thirty-second Annual Report and Statement of Account, the Council has much pleasure in stating that the progress of the Institution has been fully maintained during the year ending July 31st, 1921.

Membership.

There has been an increase of 81 in the membership, the number now on the Register being 3,425, as against 3,344 for the previous year.

Distinctions Conferred on Members.

The Council congratulates Sir Joseph Hewitt on the baronetcy conferred upon him and Sir Hugh Bell, Bart., on being made a Companion of the Bath.

During the past year the following other rewards and distinctions have been conferred upon members:—**O.B.E.:** Prof. Henry Briggs, John C. Brown, and Walter Herd; **I.S.O.:** Griffith John Williams; **Officer de l'Ordre de Leopold:** Lt.-Col. Francis Ivan Leslie Ditmas; **Mentioned in Despatches** (three times): Walter Herd.

Obituary.

The Council regrets to record the death of the following 49 members during the past year:—Edgar Adams, George Francis Adams, Herbert Ainsworth, Sir Ralph Percy Ashton, Sir William Scott Barrett, William Henry Brealey, William Clifford, Sir Gilbert Claughton, Bart., Joseph Cook, Samuel Cranshaw, Hugh Crichton, George Alexander Curry, Francis Davison, David Watson Dixon, George Dixon, Alexander Faulds, Barnabas Fenwick, Lancelot Holstock Fletcher, James Gardner, Thomas Gill, Benjamin Phillip Griffiths, J. Povey Harper, William Herdman, Jacob Higson, W. Hutchinson, Christian Korte, Ralph Lidster, Henry Johnson Mein, Henry Johnson Mein, Junr., Thomas Wilfred Howe Mitchell, Raymond Nadin, Tom Noden, William David Owens, Hon. Edward Gawler Prior, Akula Varatharaj Ethi Raj, George Henry Robinson, Junr., Ralph Richardson, George Albert Roberts, Charles F. Scott, Frank Simon, Sydney A. R. Skertchley, Arthur Sopwith, William Statham, Walker Oswald Tate, Henry William Taylor, George Blake Walker, Hugh L. Wilkinson, Sir Lindsay Wood, Bart., and Sir Thomas Wrightson, Bart.

Sir Lindsay Wood, Bart., was a Past-President of the Institution and a distinguished mining engineer. Both as President and as a Member of Council he rendered splendid and continuous service not only to the Institution but to the whole mining world by his wise counsel and sound advice, and by his steadfast commonsense and example.

Mr. Arthur Sopwith and Mr. George Blake Walker were also Past-Presidents of the Institution and eminent mining engineers. As Members of Council and for many years Members of the Finance and Publications Committee, these gentlemen rendered valuable assistance to the Institution.

Col. T. W. H. Mitchell was a member of the Institution since its foundation in 1889, and for many years served on the Council and on the Finance and Publications Committee.

Memorial Tablet.

The Memorial Tablet which the Council decided to place in the Council Chamber of the Intitution, to perpetuate the memory of those members of the Institution who gave their lives during the Great War, has now been completed by Mr. A. G. Wyon, King's Medallist, and the Tablet will be unveiled at a date to be announced later.

Co-operation with The Institution of Mining and Metallurgy.

An important change in the administration of the Institution has taken place during the year.

For some time past the Council has been considering questions connected with the development and future policy of the Institution, and discussions have taken place on the lines of getting into closer co-operation with The Institution of Mining and Metallurgy, particularly in regard to housing and general administration. The lease of the Institution premises at 39, Victoria Street, Westminster, will shortly terminate, and it therefore became necessary to consider the question of new accommodation and a general re-arrangement of the establishment to meet its present needs. After discussion between the two Councils, it was considered that in the best interests of the mining engineering profession and in the interests of this Institution greater strength and advancement could be secured by a closer co-operation of the two Institutions, particularly in matters of policy. As a result of these negotiations, the Council at its meeting in Leeds, on March 16th, 1921, after most careful consideration, resolved that The Institution of Mining Engineers should be housed with The Institution of Mining and Metallurgy, that the office administration should be combined, that there should be one Secretary to the two Institutions, and that the Libraries should be combined (the books, of course, remaining the property of each Institution), but that the financial arrangements should still be controlled by the respective Councils as at present, and the identity of each Institution maintained.

The Institution has now moved to Cleveland House, 225, City Road, E.C.1, and Mr. C. McDermid, the Secretary of The Institution of Mining and Metallurgy, has taken over the duties of Secretary of The Institution of Mining Engineers. The general arrangement is that during the two years from July 31st, 1921, the actual cost for rent, rates, staff, etc., will not be increased, and that any change which may thereafter take place will be in proportion to the existing expenses of the two Institutions.

A Joint Advisory Committee has been constituted to deal with all matters affecting the mutual interests of the two Institutions.

President-Elect.

Prof. Sir John Cadman, K.C.M.G., D.Sc., has been nominated for election as President of the Institution for the year 1921-1922.

Institution Representatives.

The Institution Representatives on the various bodies and societies remain the same as for last year. In addition, Sir John Cadman, K.C.M.G., and Mr.

Wallace Thorneycroft have been appointed to represent the Institution on the Committee for Mining and Metallurgical Machinery formed by the British Empire Exhibition.

Honorary Members.

Sir Aubrey Strahan, K.B.E., late Director of the Geological Survey of Great Britain, and Mr. William Walker, C.B.E., late H.M. Chief Inspector of Mines and now Director of Health and Safety, Mines Department, have been re-elected Honorary Members of the Institution. Dr. J. S. Flett, O.B.E., Director of the Geological Survey of Great Britain, has been elected an Honorary Member.

Institution Medal.

The Council, after careful consideration, considered it inadvisable to award any Medal for the year 1920-1921.

Training of Mining Engineers and Colliery Managers.

The Committee appointed to frame a scheme or schemes for the training of mining engineers and colliery managers has submitted as an interim report a memorandum *re* membership of the Institution. The Committee now proposes to proceed with the second part of its work, namely, to consider a scheme for the training of mining engineers.

Civil Engineers (Registration) Bill.

The Council has been notified by The Institution of Civil Engineers that it is not now intended to proceed with the Bill proposed in 1920 to provide for the registration and to regulate the qualifications of Civil Engineers. Application has, however, now been made to H.M. Privy Council for a supplemental Charter to authorize the use of the description " Chartered Civil Engineer " by corporate Members of The Institution of Civil Engineers.

" The Control of Atmospheric Conditions in Hot and Deep Mines " Research Committee.

The experimental work of this Committee, working with the Advisory Council for Scientific and Industrial Research under the Chairmanship of Sir John Cadman, has been continued during the past year, and the Committee presented a Third Report (read and discussed at the General Meeting in London), containing an account by Mr. J. P. Rees of observations on the dry- and wet-bulb temperatures in the different parts of several deep mines in England and Scotland, with an analysis of the various factors on which the observed temperatures depended. The influence of ventilation in controlling the temperature, and more particularly the wet-bulb temperature, of roads and working-faces appears clearly from this report.

An account by Mr. J. Ivon Graham of the geothermic gradient in different British coal-mines is nearly complete. This and other work of the Committee has been delayed by the recent coal-stoppage, but the observations and experiments are now again in progress.

Mining Legislation.

The Council has appointed a permanent Committee of the Institution to consider any proposed legislation affecting mining technology.

Interchange of Members.

The Council recommends that an arrangement should be made whereby a member of any Federated Institute shall have the privilege of attending the meetings of any other Federated Institute and of receiving notice of such meetings on payment of a sum not exceeding 2s. 6d. per annum towards the expenses of that Institute.

Library.

During the year 38 books have been added to the Library, which now contains 2,748 volumes.

PUBLICATIONS.

Four Presidental Addresses and thirty-eight papers have been printed in Volumes LX. and LXI. of the *Transactions*, exclusive of a number of abstracts of foreign and colonial papers.

The Council has decided to issue bound volumes of the *Transactions* to members who wish to receive them in that form instead of in monthly parts, on payment of the cost of binding, etc.

Owing to the serious increase in the cost of paper and printing, the Council decided to print the *Transactions*, commencing with Volume LX., in smaller type which allowed of fifty-four lines to the page as against forty-seven in the past, and to make a slight increase in the width of the printed page.

FINANCES.

The invested funds of the Institution remain unaltered at £17,730 3s. 7d.

Owing to the deficiency of £681 0s. 1d. incurred in the previous year's working, the Call per member participating in the privileges of the Institution was raised from 20s. to 25s. during the year just ended. In order, however, to meet the increased expenditure estimated, the Call for the year 1921-1922 has been fixed at 27s. 6d. per member.

The Statement of Accounts submitted herewith shows the ordinary income for the year ended July 31st, 1921, to have been £6,391 5s. 9d., as compared with £5,404 3s. 11d. for the previous year. The expenditure amounted to £6,391 7s. 2d., as compared with £6,085 4s. 0d. for the year 1919-1920. The balance of assets over liabilities, exclusive of the invested funds and the value of the stock of *Transactions*, but inclusive of the value of the furniture and fixtures (after allowing for depreciation), now stands at £3,156 10s. 5d., as against £3,156 11s. 10d. for the previous year.

On the motion of the President, seconded by Mr. C. C. Leach, the Annual Report and Accounts were unanimously adopted.

The Institution of Mining Engineers: Abstract of Income-and-Expenditure Account for the Year ended July 31st, 1921.

Expenditure.	Year 1920-1921. £ s. d.	Year 1919-1920 £ s. d.
To Printing *Transactions*, advertisements, excerpts, advance proofs, etc. ...	2,792 5 10	2,886 11 10
,, Postages	390 2 10	404 8 7
,, Stationery and incidental expenditure ...	322 8 3	296 19 7
,, Salaries, indexing, travelling expenses, etc.	1,813 15 0	1,780 7 7
,, Office rent, cleaning, lighting, etc. ...	536 6 8	476 15 4
,, Cost of meetings	34 17 9	94 18 11
,, Commission on advertisements	168 9 10	145 2 2
,, Legal charges	33 1 0	0 0 0
,, War Memorial Tablet	300 0 0	0 0 0
	£6,391 7 2	£6,085 4 0

Income.	Year 1920-1921. £ s. d.	Year 1919-1920. £ s. d.
By Capitation fees	4,254 2 6	3,322 0 0
,, Sales of *Transactions*, excerpts, etc. ...	589 15 0	698 18 1
,, Advertisements	673 19 5	580 8 9
,, Interest from investments, etc. ...	616 10 6	624 1 1
,, Reclaimed income-tax	178 16 0	178 16 0
,, Amount overestimated for printing the concluding parts of *Transactions* for the year 1919-1920, etc. ...	78 2 4	0 0 0
	6,391 5 9	5,404 3 11
Deficiency...	0 1 5	681 0 1
	£6,391 7 2	£6,085 4 0

Abstract of Balance-sheet.—July 31st, 1921.

Liabilities.	Year 1920-1921. £ s. d.	Year 1919-1920. £ s. d.
Sundry creditors	969 18 6	922 14 2
Balance of assets over liabilities	18,186 14 0	18,186 15 5
	£19,156 12 6	£19,109 9 7

Assets.	Year 1920-1921. £ s. d.	Year 1919-1920. £ s. d.
Sundry debtors	315 8 3	296 6 5
Investments at cost ... ... (actual value of above at July 31st, 1921, £12,168 16s. 1d.)	17,730 3 7	17,730 3 7 (actual value of above at July 31st, 1920, £11,958 2s. 6d.
Interest accrued	281 9 7	281 9 7
Cash at bank	715 18 3	720 14 10
Office furniture (*less* depreciation)	113 12 10	80 15 2
	£19,156 12 6	£19,109 9 7

ELECTION OF OFFICERS, YEAR 1921-1922.

The election of officers for the year 1921-1922 was announced, as follows :—

PRESIDENT :

PROF. SIR JOHN CADMAN, K.C.M.G., D.Sc.

VICE-PRESIDENTS :

Mr. J. R. L. ALLOTT.
Major T. P. BARBER, D.S.O.
Mr. VINCENT BRAMALL.
Mr. W. F. CLARK.
Mr. T. Y. GREENER.
Mr. J. H. W. LAVERICK.
Mr. C. C. LEACH.
Mr. W. D. LLOYD.
Mr. R. MCLAREN, M.P.
Mr. SAM MAVOR.
Mr. H. E. MITTON.
Mr. DAVID M. MOWAT.
Mr. A. J. A. ORCHARD.
Lt.-Col. F. R. SIMPSON.
Mr. JOHN SIMPSON.
Mr. SYDNEY A. SMITH.
Mr. J. R. R. WILSON.

AUDITORS.

Messrs. J. G. Benson & Sons, Chartered Accountants, Newcastle-upon-Tyne, were re-elected the Auditors for the year 1921-1922.

Prof. HENRY LOUIS (Newcastle-upon-Tyne) : It is my very pleasant task to ask you to accord a very hearty and sincere vote of thanks to the Retiring-President for his conduct of the affairs of the Institution during his tenure of office. Fortunately, it requires no long speech from me, for his record speaks for itself, not only because of the admirable way in which he has presided over the meetings of the Institution, but because of the immense amount of work which he has done in Council meetings and Committees during the two years in which he has held office as President. To my mind, Col. Blackett typifies most thoroughly, and has typified most thoroughly in his tenure of the chair, the objects of our Institution. Our Institution has not been founded or carried on with any selfish or individualistic object. Our purposes have been throughout the advancement of the mining industry, and the improvement of conditions of efficiency and safety in that industry; and in that respect I venture to think that Col. Blackett's own record must take high rank. Furthermore, his tenure of office will always be handed down in the history of our Institution as noteworthy especially for an act which will, I am convinced, tend to the advancement of the whole mining industry, namely, our closer union with The Institution of Mining and Metallurgy. It is exceedingly fortunate for this Institution that this movement came about when we had for President a man of such original and sound thinking power, and a man who had so thoroughly the courage of his convictions as Col. Blackett, and we are greatly indebted to him for the exceedingly able way in which he has carried this somewhat difficult matter to a satisfactory conclusion. Without saying any more, I would ask you to accord to Col. Blackett our sincere thanks for his conduct of the Presidency during the past two years of the Institution, and I will ask Mr. Allott to be good enough to second the resolution.

Mr. J. R. L. ALLOTT (Kidsgrove) : It is with the greatest possible pleasure that I second the vote of thanks to our Retiring-President, Col. Blackett. Prof. Louis has ably explained Col. Blackett's attainments

and work in connexion with the mining industry. It needs no further words of mine to remind you of all that he has done in that direction; and I have great pleasure in seconding that our best thanks be given to Col. Blackett for his valuable services to The Institution of Mining Engineers.

The resolution was carried with acclamation.

The Retiring-President: In quitting the Presidency of our Institution, I would like my farewell words to express, however inadequately, my sense of the great honour which has been mine for the past two years, and of the consideration which I have received from the Council and members generally. I am deeply conscious that my health has to some extent interfered with the performance of my duties; but, owing to the kindness of all, and particularly of your President-Elect, I have not altogether failed. The time has been made memorable by two events—the one, our co-operation with The Institution of Mining and Metallurgy, the importance of which will, I hope, be found in future to be as the planting of a seed is to the growing of a great tree; and the other, the great and disastrous coal-stoppage. As to the former, I believe that the movement will grow until it embraces all that is most capable and high-minded, not only in our nation, but in the whole world of English-speaking mining engineers possessed of unselfish character and great scientific aims. As to the latter, the coal-stoppage, our Institution is to be congratulated that it has kept its purpose and conduct clean during very dirty times, and that it has added no friction to red-hot surfaces, but rather that its influence has been beneficial and dignified. Charged, however, by its Charter with the welfare and safety of coal-mining, the Institution cannot but regard the position which has now arisen with both anxiety and dismay, for the coal industry has emerged as though convalescent from a serious disease—weak, trembling, although perhaps somewhat purified. The question of complete recovery remains yet to be answered. Can the convalescent ever fully recover, or within a time not discounted by age? If the answer is "yes," then how long will it take, and by what process of further cure? If "no," then to what extent will disability remain? These are very serious questions, and not easily answered even with the help of time. For a hundred years coal has been supplying Britain with energy to produce luxuries beyond the reach of other nations of the world; but now her coal-seams are becoming more difficult of access and of decreasing section, while other nations in the race to overtake her have found easier seams than Britain ever had, and are themselves able to deliver a superabundance of luxuries from their "bottled sunshine" of millions of years gone by. If it is true that Great Britain has been caught up by these thicker and easier seams of other nations, how then shall she be able with her thinner seams to work less time at them or employ more men to produce less result? Nay, how shall she be able to work at all the still thinner seams measured by inches which before the great war she was bravely struggling to exploit? Make all the allowance possible—that she has the coal under her feet and at every port, and has quality beyond compare—and the answer is still in doubt—can it be done? Then when you have considered this, you will remember with a sinking heart that oil is now to be reckoned with. The quarrel between the partners in the coal industry furnished the greatest opportunity for advertisement which oil has ever had. It is difficult to say where and for what purpose

oil has not been used. From cooking in the cottage to driving the mightiest mill, oil has been gratefully used by one and all. Even collieries themselves, with coal beneath their feet, use it for purposes which hitherto were served by either steam or horses; and the internal-combustion engine provides a holiday trip for the miner on the day made idle because his locomotive needs no coal. And yet, despite this rush to oil, there is so great a plethora that storage is being sought to-day at huge expense to avoid waste and glut. At the present moment British coal is at least four times as dear in our nominal money as it was some thirty years ago, and while much of this increase is due to decrease in value of the money token, and some is also due to the great difficulty in the getting of more inaccessible and less favourable coal-seams, much more is accounted for by the greater wages paid for less time worked; and, as against the better conditions of American and other coming coal nations, I see no remedy, however partial, until greater individual efficiency in terms of time and labour can be once again restored. In the light of the increase in scientific knowledge, there are also a great many expensive and more or less unnecessary rules and regulations for mines, enforced in the name, and name only, of safety, which should either be entirely abolished or considerably modified in the interest of true and safe economy.

I can only conclude by once more expressing my gratitude for the way in which you have always supported me through my term of office. It is my duty now, the King being dead, to sing "Long live the King," and to induct into the chair Sir John Cadman for the coming year. From every point of view the members of this Institution could not have selected any better President for the Institution during the next few years than Sir John Cadman. The next two years are going to be difficult years, and it is going to take an able man to steer our Institution through them. I myself feel that our next two years are to be more difficult for the coal industry and those that pilot it than the years that have gone; and I am indeed glad that we have got a young, vigorous, and capable President to run our affairs. I have the greatest admiration for Sir John Cadman, and I have no fear of the way in which our business will be conducted: it will be done excellently well and entirely to our satisfaction. I therefore hand over the chair of the Institution to Sir John Cadman.

Sir John Cadman then took the chair, and delivered the following Address:—

PRESIDENTIAL ADDRESS.

By Prof. Sir JOHN CADMAN, K.C.M.G., D.Sc.

To occupy the Presidential chair which has in the past been filled by such distinguished members of the mining profession is no easy task, and I am very sensible of the honour you have done me in thinking that I shall be equal to it. Two circumstances add to my gratification. The first is that I take over the reins of office at a meeting held in my native County of North Staffordshire and under the wing of a local Institute to which I owe so much. The second is that the last President to be elected from this immediate neighbourhood, eighteen years ago, was my own father.

As you are aware, some important changes have just been made in the London administration of The Institution of Mining Engineers. So far as our London offices and Secretary are concerned, we have joined forces with The Institution of Mining and Metallurgy, and we have done so with the full confidence that the results which may fairly be expected from the closer co-operation will widen our sphere of usefulnesss, and make the Institution of greater value both to its members and to the industry which it is our responsibility and our privilege to support.

We represent, I need hardly remind you, an amalgamation of seven different and distinctive local Institutions of Mining Engineers. But the objective of each and all of our units and of the Institution itself is the same. It is to advance the knowledge of the scientific principles underlying mining, and to raise the profession to a state of constantly increasing efficiency.

In so complex an enterprise as mining it is not easy, nor is it desirable, to dissociate the human and financial sides from the purely scientific side. But what we as a body have to remember is that our primary functions lie in the development of the industry from a technical and scientific standpoint, and that we must not allow ourselves—it would, indeed, be fatal—to waste our energies on outside polemical controversies of any description, political or otherwise. Our business is to promote efficiency throughout the whole area of our profession by research and counsel and guidance, and also by practice, and to regard this as the supreme end of our existence and activities.

The Mining Industry has behind it such traditions, such a volume of past history and experience; has played such an important part in the development of our nation; so much of the wisdom of our predecessors is embodied in it: that its whole fabric needs to be carefully understood before any efforts are made to remodel it by legislative enactment. There are very few spheres in which the amateur reformer is so likely to go astray and to do more harm than good, and in which it is so necessary that the past and its legacies should be thoroughly understood before any experimental revolution is contemplated.

It is often and truly said that ours is a coal civilization. The history of British coal-mining is the history of British industrial progress. Pretty nearly everything that Great Britain is in the world of commerce and industry, she owes to her coal and to the happy accident that has placed most of the coalfields near the coast. Coal supports the

whole edifice of our material prosperity. Our wealth, our manufactures, our shipping, our Navy, our power in war, our ability to recover from its effects, all depend on coal. Coal is the maker of modern Britain, and those who discovered and developed the methods of working it have done more to determine the form of British social development and the bent of British activities than all the Parliaments of the past hundred and twenty years.

Without coal we should sink to be a second Denmark. It is doubtful whether we could maintain even a third of our present population. Had it not been for coal and the discovery of how to use it in smelting iron the Britain of to-day might be scarcely distinguishable from the Britain of the eighteenth century. Our command of cheap fuel formed the basis and the starting-point for the tremendous, up to then unprecedented, material advance registered by Great Britain between 1800 and 1870. And it is still our mainstay. Not only does the coal industry support some five millions of our people, not only did it represent before the war over a tenth of the total value of our exports and over seven-tenths of their bulk, but it continues to animate and sustain every form of manufacturing enterprise, and its by-products are the essential raw materials of a host of lesser but still vital trades.

There is, in short, no industry so indispensable to our existence and prosperity, whether as a nation or as individuals, as the coal industry. By means of it we pay, or we used to pay, for our huge intake of foodstuffs and raw material. We sent out our vessels loaded with coal, and the same vessels returned loaded with the products and commodities needed in our homes and factories. Each operation was cheap, because each worked in with and supplemented the other. Coal, therefore, is more even than the supreme source of heat, light, and power. It is—or rather it was before the war, and we must see to it that it becomes so again—a key export, the most powerful of all magnets to attract to these shores the food we eat and the raw materials we handle in our workshops.

But even here we do not exhaust the importance of coal in the national economy. A century ago we were practically a self-supporting people. We can never become so again. The security we once possessed through growing on our own soil a sufficiency of foodstuffs for our own people we have voluntarily relinquished; and it is just because we have relinquished it that nearly fifty millions of people are able to live in the British Isles, and that the adventuring spirit of British manufacturers, merchants, capitalists, and workers has spread our interests throughout the universe. The miracle of British power and achievement depends on our boldness in going forth and laying the whole world under tribute on a smaller reserve of home-grown produce than has ever been known in the history of this or any other land. We might have been safe, self-contained, and negligible: we have preferred to be great, populous, powerful, and to run transcendent risks. The price we pay for our world-wide activities and influence is that for forty odd weeks in the year we rely upon other countries to send us the means of maintaining life, and the raw materials to keep our factories going.

Now, in this marvellous and unparallelled equilibrium of commercial forces that centres in the British Isles, coal plays a two-fold part. In the first place, as I have said, by exporting it we help to pay for the foodstuffs without which we starve, and for the raw materials without which we cannot work. If we cannot export it, if our vessels can no longer find a market for coal abroad, if they have to make the outward trip in ballast, then the homeward freight as a necessary consequence will have to

be raised to cover the expense of both voyages, and to that extent we shall be adding to the cost of living and of industrial production. Small exports of coal, or no exports at all, spell dearer imports for everybody.

In the second place we in Great Britain stand or fall by the ability of our towns to sell their products all over the world in rivalry with all other peoples. We have issued a sort of manufacturing challenge to the entire universe. If our foreign trade were to be lost to us our cities would decay, and the whole economic basis of this country would collapse. We have staked everything on our industrial capabilities, which means on the efficiency of our manufacturers in producing and marketing better goods or goods at a lower price than any or all competitors. But our industries can only face this ordeal and survive it if they have a constant supply of cheap power, and cheap power at present and for as long as any of us can foresee can only be had from coal. Coal, in other words, is the foundation of that export trade in manufactured goods by which this nation lives.

We have been mining coal in Great Britain for six hundred years and more. Enough of it, easily worked outcrop coal, of course, was burned in London in the 16th century, by way of supplementing the growing shortage of timber supplies, to attract the notice of the legislators and to lead to forbidding its use as a public nuisance on account of its offensive smoking properties. But it was not until iron-smelting by coal and the development of the steam-engine became factors in British industry that the value of our Coal-Measures really began to be realized. In railways, steamships, and manufactures they enabled us to lead the whole world, and the energy and adaptability of our people did the rest in setting the pace for the industrial transformations of the past century.

Now I am not one of those who take a despondent view of the future of this basic industry, grave and manifold as are the difficulties with which it is now contending. I believe in its capacity for recuperation and readjustment, and I believe also in the strong good sense of the British stock. When a thing has to be done they usually find a way of doing it, and there can hardly be much question that one of the things that most need to be done is to re-establish the coal industry on as firm a footing as it held before the war.

At the same time I am not blind to the fact that within the last two decades certain detrimental influences have crept into the coal-trade and seriously menaced its efficiency. Take, for instance, the questions of prices and of output per person. I will not confuse you by reading all the statistics which I have prepared, but I will briefly summarize their results. In 1900 the output of coal was 291 tons for every person employed in the industry; in 1920 it had fallen to 183 tons; for the first three months of the present year it had declined still further to 177 tons. If it is objected that 1920 was an abnormal year, I am quite willing to substitute the last of the pre-war years, 1913. In 1913 the output per person was 258 tons as against 291 tons in the first year of the century (see Appendix A).

These figures reveal a situation which cannot be too seriously examined. It may be that the exhaustion of thicker and more accessible seams and the working of deeper and thinner seams, and the extension of underground transport of coal have contributed to the reduction. It may be, as some have contended, that the industry is overmanned, and that there is a surplus labour force mostly above ground which adds nothing to the productive capacity of the collieries employing them. It may be that all British industry has been passing through one of those

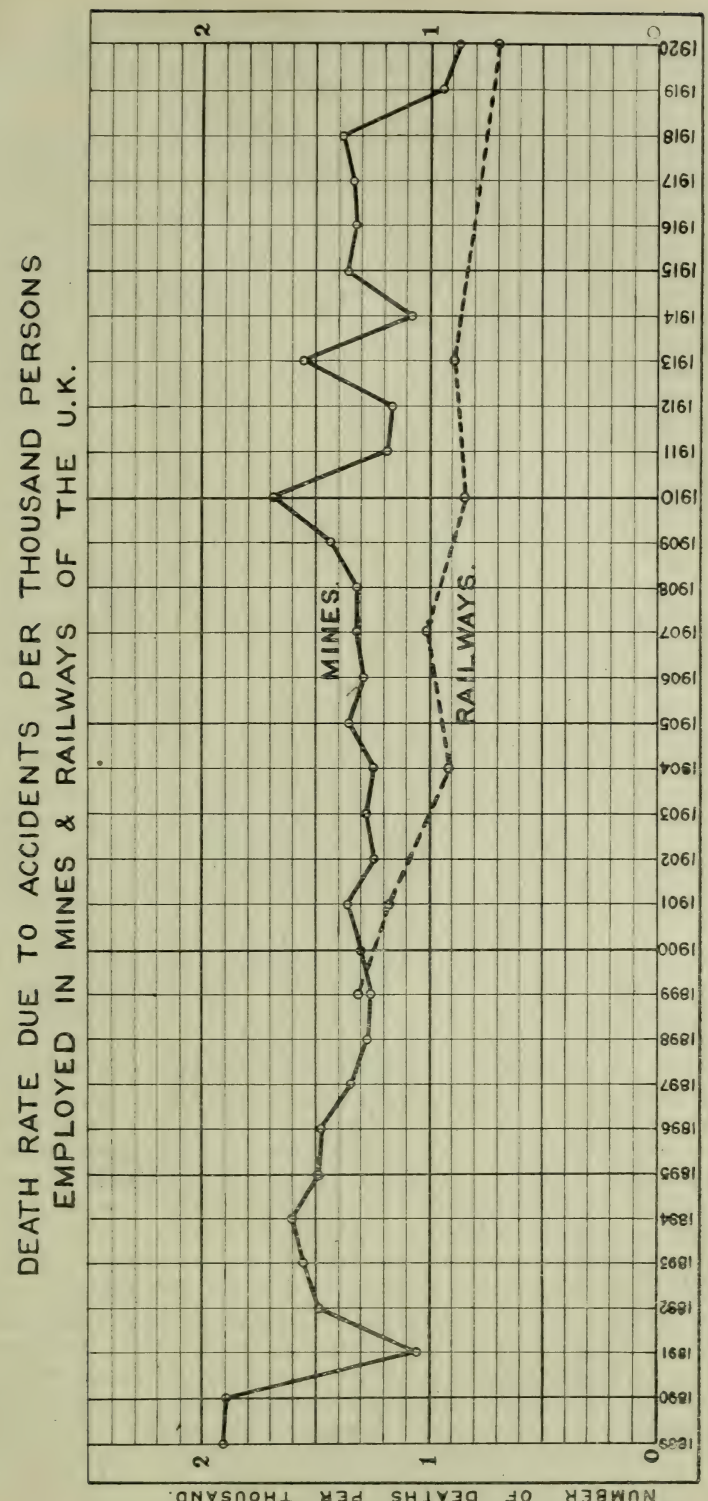
lazy fits that often seem to recur in its history, and that are always sooner or later shaken off; and that the relative decline in the individual output is merely a symptom of a general slackening of effort. But I do not think that these factors really explain the falling-off. In my view there is another cause which operates even more effectively to restrict output—and that cause is over-legislation.

During the past two decades coal-mining has been subjected to a degree of political and legislative interference without parallel in any other industry. There have been ten major Acts passed since the beginning of the century directly regulating the operations of coal-mining, and something like 100 Statutory Orders, and in addition there are a considerable number of other Acts with clauses in them affecting the industry (see Appendix E). These enactments have so circumscribed the initiative of both managers and miners in matters that might much better have been left to their own discretion, and have so fettered the freedom of action and of choice, as to stifle the natural spirit of energy and enterprise which characterizes our people. When in a mine or in any other undertaking you get a whole series of prohibitions and restrictions and regulations imposed by an outside authority, you are bound also to get an atmosphere lacking in the essential element of personal responsibility. Managers and workmen are equally affected by it: their relationship is at once made more artificial than it need be; there is a definite loss all down the line of interest, harmony, and the will to work.

Please understand that I do not advocate any abridgment of that control which the State should properly exercise over the mining industry in order to safeguard the lives and health of those engaged in it. Such control is essential, and undoubtedly it has helped to make the British mines what they are—the safest in the world. But the legislation of which I am speaking goes far beyond that. It is fussy, ill-conceived, the product much more of political pressure than of a knowledge of working realities, and it has blunted the edge of incentive and placed artificial barriers in the way of co-operation and team-play between employers and employed.

An interesting comparison suggests itself here with the railways. Both are hazardous occupations; both have been the objects of a great deal of legislative solicitude. But this solicitude has been carried much further in the case of the mines than of the railways. The number of Railway Acts passed by Parliament in the last fifty years is insignificant compared with the number of Mining Acts. Railway directors and managers may be surprised to hear it, but it is none the less a fact that relatively they have been almost neglected by the Legislature. One might therefore expect to find that the death-rate from accidents on the railways had diminished much more slowly that the death-rate from accidents in the mines.

Such, however, is not the case. I have here the statistics of mining casualties going back to 1873 (see Appendix C). When you see them in print I think you will agree they constitute a record of progressive improvement which reflects the utmost credit on the Inspectors of Mines, managers, and miners. At this moment I will indicate only briefly what they reveal. They reveal a steady decline in the number of fatal accidents from 1·26 per 1,000 in 1899 to 0·88 in 1920. But the railway statistics for the same period show an even greater decline (see Appendix D). In 1899 the death-rate from accidents on the railways was 1·31 per 1,000 persons employed; last year it was 0·71. In other words, in the


DEATH RATE DUE TO ACCIDENTS PER THOUSAND PERSONS EMPLOYED IN MINES & RAILWAYS OF THE U.K.
MINES.
RAILWAYS.
NUMBER OF DEATHS PER THOUSAND.
0
1
2
1920
1919
1918
1917
1916
1915
1914
1913
1912
1911
1910
1909
1908
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1890
1889

past twenty years the falling-off in casualties has been less pronounced in the mines than on the railways, though the former have been well-nigh suffocated under legislation, while the latter have escaped comparatively lightly.

I believe there is a deduction which may safely be drawn from all this. It is that hasty and inappropriate laws may easily diminish output without promoting safety. In spite of—or because of—the enormous mass of legislation which has been dumped upon them, the owners, managers, and miners have not succeeded in cutting down the death-rate as fast proportionately as the relatively unencumbered owners, managers, and workmen of the railways. On the other hand, a part, I think myself a considerable part, of the reduction in output per man is directly traceable to superfluous and badly-devised laws. They have cast a blight over the industry; they clog its operations; they retard its recovery to-day; and I do not hesitate to assert that what coal-mining in Great Britain most needs is a respite from the well-meant but bungling attentions of Parliament.

Possibly the new Department of Mines may serve as a protection, though I need hardly say that no one who is concerned with the efficiency of the coal industry wishes to weaken the control of Westminster in order to strengthen the control of Whitehall. But now that the mining industry has a Department and a Minister of its own there is at least a prospect that the Government, if and when it is again called upon to legislate, will have at its disposal expert and responsible advice. The new Department has at any rate made a good start, and its policy of stimulating co-operation between the interests concerned in the industry—interests that are far more willing to co-operate than the public quite realizes—is full of hope.

Again, the sort of State control which existed during the war is at an end, and I do not observe, on the part of any section of the mining industry, or of the nation, any uncontrollable longing to see it re-established. The abnormal conditions under which the colliery manager became a kind of superior accountant, while the miners wrangled about subsidies, and rather forgot about production, are passing, and with them will pass, I believe, much of the inefficiency and lethargy, and the artificial ill-will which they provoked. The industry after the tremendous upheavals of the past seven years has not yet settled down. But it is gradually righting itself. It sees what it has to do if it is to continue to render its old and incomparable services to British welfare. It must bring back output to the pre-war figure; it must recapture its foreign markets; it must reduce the pithead price to a level that will enable our manufacturers to sell their goods abroad. And it sees also that these very arduous, but wholly indispensable objectives, can only be carried if the industry is at peace, and if its conduct is regulated by an energetic harmony and goodwill.

I have spoken of the services of coal-mining to British welfare, but it is right I should interject a reminder that the coal industry does not minister to other British industries one whit more than it is dependent upon them; in the long run it rises or falls with them, and as their well-being is determined by the complex interplay of forces and conditions which operate all over the world, it follows that the coal-trade itself is equally subject to these external factors and influences, and can only flourish so long as it recognizes and allows for them. For example, the pithead price is the chief factor which will determine whether we can recover our foreign markets and at the same time enable our manufacturers to compete effectively abroad; and the level to which for these

purposes the pithead price must be reduced will be fixed, not by the cost of living at home, or by the desire of the miners to get higher wages, or of the owners to reap larger profits than the industry can afford, but by the action of foreign competition partly in the coal-trade itself, and partly in all the other branches of manufacturing activity. Like every other British commercial interest the coal industry is intimately affected by world-conditions, and all our schemes for regulating wages, hours, and output in the light of purely local circumstances will eventually go to pieces unless we remember this.

I pass on to consider the chances, such as they are, of getting cheaper coal and of using it more economically. It is an auspicious development, to which this Institution has contributed much in the past, and stands ready to contribute even more in the future, that these two problems of an improved technique and of a more scientific utilization are now receiving the attention they deserve. The engineer and the chemist, in my judgment, will prove the real saviours of the British coal industry. To the uninitiated the way of salvation seems easy. He compares the individual yield of the British and the American miner; he reads of the extent to which coal-cutting machinery is used in the United States; he ignores the total dissimilarity of conditions in the two countries, and he writes off at once to his favourite paper, and lays it down that more and better machinery is what is needed in the British pits. His comparisons, of course, are faulty, and his deductions as a rule exaggerated, but there is this amount of truth in what he says—that a more general application of mechanical methods would undoubtedly benefit the mining industry in this country. Every engineer, I think, recognizes as much; but every mining engineer also recognizes that the obstacles to the introduction of new and better machinery are human and psychological rather than financial and technical.

The effort to furnish our collieries with thoroughly up-to-date mechanical devices must not and will not be abandoned. But the opposing barriers of inertion, or prejudice, or economic ignorance are formidable; progress will be constant, but it will be slow; and the idea that the price of coal can be reduced overnight by ordering a few hundred or a few thousand machines and installing them in the mines has a simplicity about it which makes it more attractive to the public than to such a gathering as this. Looking at the question broadly, there is more waste in using coal than in getting it; and here I certainly think it should be a point of pride with all colliery managers and engineers to bring down their own fuel consumption to the minimum. An effective fuel control, with a heat balance-sheet, ought to be a feature of every efficient colliery. If all the collieries in the kingdom had modern plants of the best description, it has been estimated that their consumption of coal, which averages from 6 to 8 per cent. of their output, would be about half what it is to-day. I venture to think that in a matter of this kind it is up to the colliery managers and engineers to set the finest example of efficient practice.

One point more. For some time past, particularly during the war period, the grading and cleaning of the coal has been most unsatisfactory, and a very inferior product has been placed on the market. Sir George Beilby recently quoted an analysis of the coal received by the Central Electric Supply Company during the first quarter of the present year. Its calorific value was 10,581 B.Th.U. as against 10,800 in the winter of 1914-1915; its cost was 45s. 2d. as against 14s. 6d.; and its ash content was 18·4 per cent. as against 13 per cent.—in other words, an extra

hundredweight of ash for every ton supplied. Such figures are, of course, mainly eloquent of the demoralization of the industry brought about by Government control. I am confident that every member of this Institution will use whatever power and influence he has to see that the public gets a squarer deal from private companies in this particular than was ever to be had from the State. To sharpen his zeal I should like to suggest that just as gas is now being sold on its thermic value and not in cubic feet, so coal will eventually, perhaps before very long, be sold not by weight or by any of the old haphazard standards of value but under precise calorific specifications. That is already being done in some parts of the United States, and I am confident that so equitable and efficient a practice will in time find its way into Great Britain.

I come now to one of the very few compensations of the recent coal stoppage, I mean its automatic riddance of the urban atmospheres of their customary foulness. We enjoyed for a time—though at a terrific price—a smokeless Britain. The air of London has been found to deposit 34·71 tons per square mile per month, whereas in the open country near Malvern the average total monthly deposit is only 6·63 tons. All over the kingdom the municipal authorities and public opinion are awaking to the urgency of abating the smoke nuisance. About a sixth of all the coal that is used in Great Britain is burned and, of course, largely wasted, in our ten million private dwellings. If we adopted the central heating system in our houses and used an open soft-coke fire to supplement hot-water pipes and radiators, an enormous saving of coal would be effected, perhaps as much as one-half. I have even heard it maintained that without this uncongenial resolution, and merely by the universal introduction of a proper and economical grate, we could save 20 per cent. of the coal that at present sends most of its heat up the chimney. Personally, I do not believe that our people will ever voluntarily give up the cheerful, hospitable, wasteful, and mostly ineffective flaming fires to which they are comfortably and quite unscientifically accustomed. But they may be made to. A very few years may see it a penal offence to burn raw coal in any of our towns. I need not tell you that while the popular view of coal is that it is something to be burned, the scientific view is tending to be precisely the opposite. It is that coal is too valuable to be burned, that to burn it is to squander it, that the by-products of coal are of greater moment than the coal itself, and that not until these by-products have been extracted should the residuum be used for industrial or domestic purposes.

I do not say that science has yet accepted these conclusions as being definitely established. But the whole problem of fuel supply is to-day being explored with a new eagerness and on an hitherto unattempted scale; and the intelligent layman, the forward-looking business man, is beginning to pose a series of questions in which it very much concerns all of us, but this Institution in particular, to help in supplying answers. Anyone who mixes in the world of affairs and who is suspected of knowing anything about coal, finds himself constantly confronted with such conundrums as these, framed by his friends not to trip him up but because they are genuinely interested in the problems involved—Is it the true and final function of coal to be transformed into gas or electricity—to serve, in other words, as the raw material instead of the supplying agent for lighting, heat, and power? Is it possible that what raw coal did for the British in the 19th century, coal in the form of gas or electricity may do for the Britain of to-day—may serve, that is to say, as the starting point for another huge industrial advance, and one that

will powerfully promote the health of our people? A smokeless Britain, possessing and utilizing an abundance of the cheapest power in the world —is that conceivably one of the prizes which science is dangling before us had we but the courage to seize it?

Let us make no mistake, gentlemen—our profession is to some extent on trial before public opinion. People are anxious to know, and are determined, if they can, to find out whether the most is being made of the greatest natural resource that this kingdom possesses; and if not, why not? They want to know whether a dispensation under which at least three-fourths of our coal is used directly, and without any effort being made to conserve the by-products, is a wise dispensation. They ask for a reason that will explain why Germany before the war, with a coal output of some 70,000,000 tons less than our own, was producing almost twice as much coke, about sixteen times as much patent fuel, and one-and-a-half times as much ammonium sulphate. They have heard of the great strides that other countries have made in developing powdered fuel, and they wonder why so very few plants of this kind are operating in Great Britain. They are told of the waste-gas from blast-furnaces which in Belgium and in Germany is conserved, purified, and used in gas-engines for blowing as well as for general power purposes, and they naturally enquire why in Great Britain it should not be similarly utilized.

The supreme industrial search of to-day is for cheap power. The world-wide hunt for oil and the keenness of current investigations into the most efficient use of coal are tokens of the universal demand for a fuel which will meet the clamorous needs of competitive industry. It has been said that if all steam-engines were as efficient as the best, 50 per cent. of the coal now used in raising steam would be saved. Manufacturers press one closely to know whether that is true. The advantages of a turbine over a reciprocating engine, and of automatic stokers and mechanical-draught furnaces, are all canvassed from the standpoint of saving the fuel supply, or turning it to better account. If gas-producers and gas-engines were to replace the ordinary steam-engine and boiler installation, it has been calculated that there would be a very big saving in the amount of coal now consumed for power purposes in mines and factories. The soundness or otherwise of the calculation is not material to my present purpose—the point is that problems of this kind arouse an interest to-day that they have never excited before, and that all of us who are professionally connected with the getting and utilization of coal become targets for a ceaseless bombardment of interrogatories from men who really want to know what the scientists have to say in reply.

Well, at present I am afraid neither the engineer nor the chemist has any very definite answer to return. But they are feeling their way more systematically and with better facilities and in a more helpful atmosphere of public sympathy and assistance than ever before. In this connexion I regard the institution of the Fuel Research Department of the Department of Scientific and Industrial Research, with Sir George Beilby at its head, as a development of the utmost hopefulness and significance. In his recent James Forrest lecture on "Fuel Problems of the Future," to The Institution of Civil Engineers, Sir George gave a highly interesting survey of the varied and complex considerations that arise before any reply can be made to the familiar question: Can a smokeless fuel be relied upon to enable the supplies of raw coal to be dispensed with? That is a problem which turns very largely on whether an economical and efficient apparatus can be devised for the carbonization of coal at low temperature, and whether a market can be found for the

resultant by-products. For instance, to obtain one million tons of fuel-oil for the Navy, it would be necessary to carbonize twenty million tons of coal, and the coke produced by this operation would amount to fifteen million tons. How could it be disposed of? Clearly the carbonization of coal for the purpose of supplying fuel-oil and motor-spirit would be absolutely uneconomic if the resultant coke proved unmarketable at a profitable price. The Fuel Research Board has accordingly been led on to probe into at least three very considerable problems: (1) the use and value of this coke for the direct firing of steam boilers; (2) its gasification in producers for the manufacture of low-grade fuel-gas and the recovery of its nitrogen as ammonia; and (3) its use for industrial and domestic heating (possibly under legal compulsion) either directly as it comes from the retorts, or after its conversion into briquettes.

The ramifications of the coal problem are, in fact, without end, and a new extension to them has recently been given by the increasing supply, the easy utilization, and the high calorific properties of petroleum products. The use of town gas as a fuel for industrial purposes, present methods of gas-heating, the most efficient way of employing low grades of fuel-gas for heat and power purposes, the supply of electricity in bulk, all come within its range and involve a vast series of complicated enquiries. I submit that these are problems to which we of this Institution must remain fully alive. Some, at least, of the responsibility for investigating them will devolve upon us. There is a certain justice in the complaint that Science has achieved of recent years little for coal in the way of developing, cheapening, and popularizing its by-products and its proper use as compared with what they have done for oil. It would seem as though oil and the possibilities of the internal-combustion engine had, during the past two decades, been but too successful in turning scientific research away from the problems of coal. If that reproach is based, as I think in part it may be, on fact, it is clearly one of the functions of such an Institution as ours to do what we can to remove it. It should appeal to us both technically and nationally. For Great Britain, coal, I sincerely believe, is the problem of problems. What we do or do not do in regard to coal in the next few years will give the measure of our capacity to weather the difficulties, and to grasp the conditions of the unexampled age bequeathed to us by the war.

Appendix A.—Statistics as Corrected by Prof. Henry Louis, D.Sc., etc., to Account for Extraneous Matters included in the early Government Figures.

Year.	Tons per total persons employed.	Year.	Tons per total persons employed.
1900	291·1	1911	256·7
1901	274·0	1912	242·5
1902	277·7	1913	258·9
1903	275·4	1914	234·3
1904	276·4	1915	265·5
1905	277·5	1916	253·6
1906	287·0	1917	243·3
1907	287·0	1918	225·7
1908	256·7	1919	192·9
1909	262·1	1920	183·9
1910	253·8	1921 (Jan. to Mar.)	177·2

APPENDIX B.—TOTAL COAL PRODUCED PER ANNUM PER PERSON EMPLOYED.

Year.	United Kingdom.	Canada.	Australia.	United States.
1886	312	341	333	400
1900	298	457	426	494
1906	275	439	462	596
1912	244*	472	542	660
1916	263	471	547	731
1920	193½*	449†	478†	744†

* Strike years. † 1919 figures.

APPENDIX C.—TOTAL ACCIDENTS TO COAL-MINERS IN THE UNITED KINGDOM, YEARS 1873 TO 1920.

Year.	Total number of deaths.	Number of persons employed.	Number of deaths per 1,000 persons employed.	
1873	1,069	514,149	2·08	
1874	1,056	538,829	1·96	
*1875	1,244	535,845	2·32	
1876	933	514,532	1·81	
*1877	1,208	494,391	2·44	
*1878	1,413	475,329	2·97	2·39
1879	973	476,810	2·04	
*1880	1,318	484,933	2·72	
1881	954	495,477	1·93	
*1882	1,126	503,987	2·23	
1883	1,054	514,933	2·05	2·05
1884	942	520,376	1·81	
*1885	1,150	520,632	2·21	
1886	953	519,970	1·83	
1887	995	526,277	1·89	
1888	906	549,184	1·65	1·83
1889	1,112	581,809	1·91	
*1890	1,194	632,380	1·89	
1891	1,005	667,983	1·50	
*1892	1,016	683,642	1·49	
*1893	1,060	683,008	1·55	1·52
*1894	1,127	705,240	1·60	
1895	1,042	700,284	1·49	
1896	1,025	692,684	1·48	
1897	930	695,213	1·34	
1898	908	706,894	1·28	1·33
1899	916	729,009	1·26	
1900	1,012	780,052	1·30	
1901	1,101	806,735	1·36	
1902	1,024	824,791	1·24	
1903	1,072	842,066	1·27	1·29
1904	1,055	847,553	1·24	
*1905	1,159	858,373	1·35	
1906	1,142	882,345	1·29	
1907	1,245	940,618	1·32	
1908	1,308	987,813	1·32	1·41
*1909	1,453	1,013,998	1·43	
*1910	1,775	1,049,407	1·69	
1911	1,265	1,067,213	1·19	
1912	1,276	1,089,090	1·17	
*1913	1,753	1,127,890	1·55	1·27
1914	1,219	1,133,746	1·08	
1915	1,297	953,642	1·36	
1916	1,313	998,063	1·32	
1917	1,370	1,021,340	1·34	
*1918	1,401	1,008,867	1·38	1·17
1919	1,118	1,191,313	0·93	
1920	1,103	1,248,224	0·88	

* In these years there were explosions causing death of over 100 persons

APPENDIX D.—FATAL ACCIDENTS TO RAILWAY SERVANTS IN THE UNITED KINGDOM, YEARS 1899 TO 1920.

Year.	Number of employees.	Number of fatal accidents	Per 1,000 employees.
1899	403,050	532	1·31
1900	—	581	—
1901	432,584	512	1·18
1902	—	447	—
1903	—	439	—
1904	432,138	395	0·91
1905	—	389	—
1906	—	433	—
1907	458,369	467	1·01
1908	—	380	—
1909	—	352	—
1910	451,672	382	0·84
1911	—	408	—
1912	—	360	—
1913	477,986	427	0·89
1914	—	435	—
1915	—	436	—
1916	—	405	—
1917	—	348	—
1918	—	297	—
1919	—	338	—
1920	553,591	395	0·71

NOTES.—(1) The figures for employees are given for only those years in which statements were rendered by the Railway Companies. The number of employees given for 1899 is that for December 31st, 1898, and the number given for 1920 is that for March, 19th, 1921. These figures *do not include clerks, mechanics, and contractors' servants in any year.*

(2) The fatal accidents do not include those which occurred to *mechanics* or *through servants falling off ladders, scaffolds, etc.*

APPENDIX E.

ACTS DEALING WITH MINES.

Coal Mines Regulation Act, 1872.
Coal Mines Regulation Act, 1887.
Coal Mines Regulation Act, 1887, Amendment Act, 1903.
Coal Mines Check Weighers Act, 1894.
Coal Mines Regulation Act, 1896.
Mines Accidents (Rescue and Aid), 1900.
Mines (Prohibition of Child Labour Underground) Act, 1900.
Coal Mines Weighing of Minerals Act, 1905.
Coal Mines Regulation Act, 1908.
Coal Mines Act, 1911.
Coal Mines Minimum Wage Act, 1912.
Coal Mines Act, 1914.
Coal Mines Regulation (Amendment) Act, 1917.
Coal Mines Act, 1919.
Mining Industry Act, 1920.

VARIOUS ACTS AFFECTING MINES.

Explosives Act, 1875.
Truck (Amendment) Act, 1887.
Truck Act, 1896.
Factory and Workshop Act, 1 01.
Employment of Children Act, 1903.
Workmen's Compensation Act, 1906.
Employment of Women Act, 1907.
Workmen's Compensation (Silocosis) Act, 1918.
Checkweighing and various Industries Act, 1919.
Employment of Women, Young Persons and Children Act, 1920.

In addition to the above Acts, there have been in the neighbourhood of 100 Statutory Orders issued between the years 1911 and 1921 dealing with special points affecting mines.

Appendix F.—Railway Legislation.

Year.	Subjects.
1871	Railway Regulation Act. Made notification of train accidents and holding of Board of Trade inquiries obligatory.
1893	Regulated hours of labour.
1894	Dealt further with notification of accidents.
1899	Dealt with signalling (block system, etc), continuous brakes, overtime, printing fares on passenger tickets, etc.
1900	Prevention of Accidents Bill.

In addition to the above, there have been two Orders issued since 1900.

Mr. A. M. Henshaw (Talke): It is my pleasure to ask you to convey to our President a very hearty vote of thanks for the Address to which we have had the privilege of listening this morning. He very happily commences by referring to the period of eighteen years ago when his father occupied the same honourable position. That touches a cord of affectionate memory in the minds of all of us who remember the late Mr. James Cope Cadman, and I think I am not stating too much when I say that no man in the mining industry ever left behind him more friends amongst his colleagues and amongst miners than did James Cadman. In Sir John we have a worthy son of a noble father; and for a man of his youthful years, I venture to say that no one is better known in the mining world. His career has been so active and vigorous, and his work so widely spread, that he is already a man of renown, and North Staffordshire is proud to see him in the position he occupies in the chair of our Institution. North Staffordshire has turned out a great many good men, and we are proud to see another at the head of our profession. I suppose most of you know Sir John Cadman's career, and I do not need to repeat the story. Although it is a short career, it is a very conspicuously successful one; and in occupying the chair of this Institution, I believe with Col. Blackett that we could not have had a better man. His temperament is such that in anything he undertakes he gives all that is in him, and he is a helpful man to his friends and colleagues. We have had a sample of his quality in the Address to which we have listened this morning. In the first place, he very boldly faces the difficult position that is before us; he does not mask in any way problems that we have to face both technically and commercially; and after having put before us those problems, he then touches a very proper optimistic note. He has courage and confidence in the future himself, and he has the faculty of inspiring that feeling in others. The aftermath of the war has produced for us in the coal-mining industry a position that must give us all very great concern. At the same time, the war has done one thing for us: it has taught us more than ever the value of technique and science, and the need of concentrating what we know on the object in view. In that way we won the war, and in that way we have to win back our position in the coal-trade in times of peace. We have to put into operation all our technique, all our science, all our determination to bring about what Sir John Cadman looks forward hopefully to—a restoration of pre-war conditions. His Address should be read by everybody connected with the mining industry, and by the workmen themselves. It is just as valuable and just as inspiring to the workman who reads it from the right point of view, and in the right spirit, as it is to the technical men who have heard the Address this morning. It is particularly valuable to the younger men; the burden will be very largely on their shoulders in years to come. The responsi-

bility will be great; but the honour and success will be great, too, and the younger men have such an opportunity during their early career as has never been offered before. Our technical Colleges and Universities must also realize their responsibilities and their opportunities, because they can do a great deal towards training the necessary men to carry out the progress that we all need. We have in the coal-trade, I have no hesitation in saying, the men of ability and resource—and men of performance—who realize the state of affairs to-day, and who are at the same time proud of their profession, proud of their country, and determined to restore the condition of the coal-trade to such a place as to enable the industries of this country once more to revive and prosper, so that England may take its place as the premier country in the world. We have the will to win, and I think we need not despair; and if we can just feel the enthusiasm inspired by our President this morning, I have no doubt that in the course of time the position that Sir John has outlined will be realized.

Dr. J. S. Haldane, F.R.S. (Oxford): I rise to support the motion which Mr. Henshaw has just made of thanks to our new President for the very interesting and valuable Address to which we have listened. I rise with a sense, I must say, of grievance against Mr. Henshaw, because he has taken the bread out of my mouth. He has said, and extremely well said, things which I wished to say about your President, and I can only re-echo what Mr. Henshaw has uttered. I have known Sir John Cadman, not from his earliest days—because I did not know him when he was a small boy—but since he was next to a small boy; and I knew and honoured his father. I have followed his career with the very greatest of, I will not say interest—something much more than interest—all through; and I am extremely glad that the Institution has elected him as its President. His Address contains many points of special interest to me; and I can speak as one who, though not a mining engineer, has had a great deal to do with mining engineers, and with persons of all sorts connected with the mining industry. Sir John referred to the dangers of over-legislation—I mean the inconvenience and trouble which has arisen from it in one way and another—and I wish to support very earnestly his words with regard to that matter. I have felt it for a long time. I have felt that everyone connected with the coal industry, from the Inspectors of Mines down even to the pony-drivers, are so tangled up with Parliamentary mine regulations that it is difficult often for them to move; and that a great deal of their time is thus taken up in a way in which it ought not to be taken up. I feel in a way partly guilty myself, because I was a member of, not the last, but the second last Royal Commission on Mines, on whose Report many of the regulations connected with the existing Mines Act were based. We came to a number of conclusions in that Report, and we reached them pretty unanimously. I think on the whole most people agreed with them, but we had not to frame an Act, or regulations, and we did not, perhaps, fully and properly consider the real difficulties of framing legislation and regulations which would give effect in a reasonable way to the conclusions then reached. When we saw the Act and regulations, and realized how much they were going to hamper people, we were very much concerned—I am speaking of individual members of the Commission. There was another later Commission that I also served on, which reported just before the war on metalliferous mines; and we put in at the end of our Report a clause asking that when it came to turning our Report into legislation we should have some say in the matter. The Coal Mines Report had been

interpreted by Members of Parliament and Government officials and others, and a great many things emerged that certainly we did not intend—I speak for myself, at any rate. I think every question of regulations and legislation requires very careful consideration, and particularly does it require consideration by people who know what the exact effects of it are likely to be. I am very glad that the two Institutions are appointing a Committee to deal with matters of that sort—a Committee which will come with the same standing as, for instance, the Miners' Federation has on all these matters. I have attended various meetings in London on mining questions, and I have felt very strongly that this Institution and all that it represents—it represents all that is best and highest in British coal-mining—ought to have been definitely represented at these discussions as to coming regulations and legislation. The two Institutions mean to put down their feet as regards this matter, and make the voice of the mining engineers of this country, and of scientific men associated with them, heard in matters of legislation. I should only rejoice if bodies like the Miners' Federation would take a similar step, and would send as representatives men who had really studied the particular questions legislated about; would send skilled people, and not just anybody—not just their official representatives—who could go into these questions. I am sure that on these questions the miners, the workmen, possess an immense deal of practical knowledge that would be of great service in coming to a decision on matters of legislation; and I hope that practical knowledge and skill will be forthcoming also. I wish to support every word that Mr. Henshaw has so admirably expressed about our President. I beg, therefore, to ask you now to accord to him a most hearty vote of thanks for his eloquent Address.

The resolution was put to the meeting, and agreed to unanimously.

The President: I am indeed grateful for the resolution and for the very kind way in which you have received my remarks.

THE ADSORPTION OR SOLUTION OF METHANE AND OTHER GASES IN COAL, CHARCOAL, AND OTHER MATERIALS.

By J. IVON GRAHAM, M.A., M.Sc., Assistant Director, Mining Research Laboratory, University of Birmingham.

In a paper communicated to this Institution in 1916* I showed that although coal is a solid it is capable, like charcoal, of taking up or "dissolving" considerable quantities of gases, and that in general the more easily liquefiable the gas the more readily will it be dissolved by the coal. It was shown in that paper that in the case of those gases absorbed to a lesser extent, such as hydrogen, oxygen, and nitrogen, the curves expressing the relation between gas-pressure and amount "dissolved" were practically straight lines—the absorption in these cases thus obeying Henry's Law for the aqueous solution of gases. In the case of the more soluble gases there is, however, considerable deviation from the linear equation.

This phenomenon of the absorption of gases by solids, or the withdrawal in a selective manner of dissolved substances from their solution, in the absence of, or apart from, any chemical action between the material and the gas, or dissolved substance as the case may be, is generally termed "adsorption" or "solid solution." Either of these are useful terms to cover a physical change which is not yet thoroughly understood, but which is now generally explained as one in which the molecules of the substance adsorbed are attracted to the surface, and particularly the internal surface, of the adsorbing material (charcoal, coal, or whatever this material may be) and there momentarily retained through the exercise of inter-molecular forces. The process is reversible, and depends upon the concentration in the surrounding media of the gas or substance capable of being adsorbed. As already mentioned, in the cases of the less soluble gases the quantitative relationship for this change can be expressed by a linear equation.

The investigations which formed the basis of my paper in 1916 were continued during the latter part of that year and in subsequent years. A variety of other materials besides coal, and different modifications of charcoal, were also examined from the point of their comparative adsorptive capacity, chiefly in connexion with the problem of obtaining suitable material for use in the army respirators during the years 1917-1918. Although these experiments were carried out several years ago, other work has unfortunately prevented the results from being collected together and published in the form of a paper.

It was soon found that the moisture-content of the material played a very important part in the "adsorptive" capacity of any dust, and I made reference to this in a paper read before the Midland Institute of Mining, Civil, and Mechanical Engineers in 1919.†

The influence of the presence of a more highly adsorbed gas on the degree of adsorption of a gas normally taken up in smaller quantities

* "The Permeability of Coal to Air or Gas, and the Solubilities of Different Gases in Coal," by J. Ivon Graham, *Trans. Inst. M. E.*, 1916-1917, vol. lii., page 338.

† "The Permeability of Coal to Gases. Part ii.," by J. Ivon Graham, *Trans. Inst. M. E.*, 1919-1920, vol. lviii., pages 32-39.

was also studied. In addition, the adsorptive capacity of coal-dust—both moist and dried—for methane, carbon dioxide, and nitrogen, under pressures up to 30 atmospheres or over, has been measured.

The experimental method adopted in carrying out the tests referred to above (with the exception of the high-pressure experiments) was in general principle the same, but had to be modified in details to suit the individual requirements of the different tests. For gas-pressures up to 1 atmosphere the method used was that described in my earlier paper on this subject (*loc. cit.*). This consisted in adding a quantity of the gas under examination, previously dried and measured, through a tap and by means of a glass capillary connexion to an evacuated flask containing a weighed amount of the coal-dust or other material being tested, and reading the resultant gas-pressure, when constant, on a mercury-gauge joined by a T-connexion to the glass capillary tubing between the flask and the measuring-vessel tap. The flask and as much as possible of the connexions were immersed in a constant-temperature bath. In the case of the experiment on the adsorption of carbon dioxide and methane when mixed, the modification consisted of the introduction of a wide-bore stop-cock and a bulb, with a capacity of about 80 cubic centimetres, between the flask and the capillary connecting tube. In this experiment the adsorption curve for the coal-dust (dry) and carbon dioxide up to 50 per cent. concentration (0·5 atmosphere) of the latter was first obtained by making several additions of known quantities of the gas and reading off the equilibrium pressure in the ordinary way. A definite amount of methane was then added to the apparatus and the latter allowed to stand for two days, so as to ensure equilibrium between the carbon dioxide and methane in the gas-mixture and that adsorbed in the coal.

The tap just above the flask was closed, and the sample of mixed gases in the bulb pumped out, measured, and subsequently analysed. The tap between the bulb and the flask was again opened, and the constituents of the new gas-mixture allowed to come into equilibrium by leaving the experiment between four and five hours before repeating the sampling process.

In this manner the equilibrium points were obtained for half-a-dozen mixtures of carbon dioxide and methane, and from the pressure and volume measurements and the analysis of the samples withdrawn the curves for the adsorption of these two gases by dry coal-dust have been drawn. As the carbon-dioxide adsorption is considerably greater than that of methane, the curve for the former has been drawn with ordinates of double the value employed in the case of the latter. The adsorption curve for methane by itself was independently determined on another similarly dried sample of the same dust.

The experimental results are given in Table III. and the corresponding curve shown in Fig. 2 (Plate III.). It will be observed that the points obtained for the adsorption of carbon dioxide (*a*) alone and (*b*) mixed with methane lie practically on the same curve when allowance is made for experimental error. There is, however, a marked effect on the adsorption of the methane, a considerably smaller amount of the latter gas being taken up by the coal in the presence of carbon dioxide than is the case when the atmosphere over the coal contains methane only.

Let us now turn to the effect of moisture in coal upon its adsorptive capacity for gases. The quantity of gas adsorbed at 30° Cent. by the same fine coal-dust (200 mesh) from the Barnsley Seam has been measured (*a*) when the coal sample was dried until it contained only 1·4 per cent. of moisture and (*b*) with a moisture-content of 10·4 per cent.

As was pointed out in a joint paper by Mr. James Hill, M.Sc., and myself,* coal-dust has the property of absorbing pyridine vapour with great avidity, and may pick up as much as 100 per cent. by weight of pyridine when exposed to the vapour of the latter at 30° Cent. A sample of coal was allowed to pick up 10·5 per cent. of this compound, and this sample was then tested as regards its adsorptive powers for methane. Another very interesting test was carried out, using the dried residue obtained as a result of the extraction of Barnsley Soft coal by pyridine, and subsequently with the same "residue" containing 7·5 per cent. of moisture—obtained by exposure to water-vapour. These results are given in Tables I. and II. respectively, where the figures taken from the plotted curves are also given for comparative purposes.

TABLE I.—ADSORPTION OF METHANE BY FINE COAL-DUST AT 30° CENT.: (*a*) DRIED (H_2O = 1·4 PER CENT.); (*b*) MOIST (H_2O = 10·4 PER CENT.); (*c*) PLUS 10·5 PER CENT. OF PYRIDINE, PER 100 GRAMMES OF DUST.

Experimental results.						Figure from curves.			
Dried.		Moist		Plus 10·5 per cent. pyridine.		Pressure.	Adsorption.		
Pressure.	Adsorption.	Pressure.	Adsorption.	Pressure.	Adsorption.		Dried.	Moist.	Plus 10·5 per cent. pyridine.
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres	Cubic centimetres.	Cubic centimetres.
0·109	39·2	0·107	8·4	—	—	0·10	36·2	8·0	3·52
0·232	74·4	0·216	15·6	—	—	0·20	66·5	14·5	6·1
0·355	109	0·436	29·6	0·401	12·05	0·40	120	27·5	12
0·490	141	—	—	0·605	16·4	0·60	168	40	17
—	—	—	—	—	—	0·80	210	52	21·8
0·754	202	0·881	56·7	0·805	20·8	1·00*	248*	63·8*	24*

* Extrapolated.

TABLE II.—ADSORPTION OF METHANE, AT 30° CENT., BY 100 GRAMMES OF RESIDUE FROM PYRIDINE EXTRACTION OF COAL.

Experimental results.				Figures from curves.		
Dried (H_2O = 0·34 per cent.).		Moist (H_2O = 7·5 per cent.).		Pressure.	Adsorption.	
Pressure	Adsorption.	Pressure.	Adsorption.		Dried.	Moist.
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Cubic centimetres.
0·106	44·4	0·128	7·8	0·10	44·2	6·08
0·212	85·2	0·256	17·2	0·20	86·5	11·5
0·313	133·1	0·386	22·1	0·40	160·2	22
0.528	207·4	0·515	27·7	0·60	227	32
0·755	267·7	0·772	41·0	0·80*	282*	42*
—	—	—	—	1·00*	326*	52·5*

* Extrapolated.

* "The Oxidizable Constituents of Coal.—Part i.," *Trans. Inst. M. E.*, 1917-1918, vol. lv., page 197.

The effect of the added moisture is very marked: the adsorptive capacity in the case of the coal-dust has been diminished to one-quarter of that of the dried material, whilst the addition of 10·5 per cent of pyridine has reduced the adsorptive capacity of the fine dust to a still lower value.

TABLE III.—ADSORPTION OF MIXED GASES BY 100 GRAMMES OF COAL-DUST.

Experimental results.								Figures taken from curves.				
Alone.				Mixed gases.				Alone			Mixed gases.	
Pressure.	Adsorption. CO_2.	Pressure.	Adsorption. CH_4.	Pressure.	Adsorption. CO_2.	Pressure.	Adsorption. CH_4.	Pressure.	Adsorption CO_2.	Adsorption. CH_4.	Adsorption. CO_2.	Adsorption. CH_4.
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetr's.	Atmospheres.	Cubic centimetr's.	Atm's·pheres.	Cubic centimetr's.	Cubic centimetres.	Cubic centimetr's.	Cubic centimetres.
0·012	32·2	0·06	16·9	0·165	254	0·02	5·4	0·05	90	14·5	90	11·2
0·075	120·5	0·12	33·2	0·225	319	0·07	15·0	0·10	161	28	161	21
0·195	263·5	0·18	48·7	0·25	339	0·11	23·1	0·20	285	53·5	285	37·5
0.365	428	0·31	79·8	0·30	383	0·14	28·1	0·30	380	80	380	51·5
0·500	528	0·50	122·8	0·360	432	0·22	40·8	0·40	460	100·	460	64·5*
—	—	0·705	164	0·43	483	0·275	47·5	0·50	528	124	528	75
—	—	0·835	190	0·50	528	0·39	62·7	1·00	—	216·*	—	—

* Extrapolated.

A comparison of the figures for the "residue" dry—compared with coal-dust also dry—are interesting. It will be noted that at equal pressures a third as much again of methane has been taken up by the "residue," whilst the effect of moisture is even more marked in this case, the adsorptive capacity for methane being reduced to approximately a seventh of that shown by the dry material, even though the actual amount of moisture present is less than in the case of the coal. Moisture, pyridine, or a gas adsorbed in considerable amount, have thus a decided inhibitory action, which is doubtless due to the fact that the molecules of such themselves occupy the positions on the surface of coal otherwise available for an easily-adsorbed gas, thus tending to "clog" the surface of the coal. In this connexion the effect of extracting coal with pyridine is interesting, since it would appear that this extraction process exposes a larger surface area on which the molecular forces controlling adsorption can come into play—as evidenced by the increased adsorption.

The moisture in the coal is partly adsorbed, and partly present in chemical combination with some of the coal-constituents in the form of easily-decomposable hydrates, whilst in the "residue" possibly the greater proportion of the moisture is present in the adsorbed condition. In other words, there may be actually a greater amount of *adsorbed* moisture in the case of the residue containing 7·5° H_2O than in that of the coal containing 10·5 per cent. of moisture. It may be stated here that the moisture determinations have been carried out by the method described by Mr. T. F. Winmill,* the coal or other material being heated

* "The Estimation of Moisture in Coal," *Trans. Inst. M. E.*, 1915-1916, vol. li., page 484.

in vacuo to a temperature of 105°-110° Cent., and the moisture given off absorbed in a weighed calcium-chloride tube. It has been found with Barnsley coal that no further evolution of moisture occurs even when the coal is heated to 160° Cent. *in vacuo*, and I take this as evidence that the estimations carried out at 110° Cent. or thereabouts by the vacuum method are thoroughly reliable.

The amount of moisture which fine coal- or shale-dust will pick up when exposed to air at any temperature will depend upon the pressure of the aqueous vapour in the air. With air saturated with water-vapour at 30° Cent. (86° Fahr.), 200-mesh coal-dust (Barnsley Soft) has been found to pick up moisture to the extent of 9·4 per cent., whilst stone-dust of similar fineness took up 4·7 per cent. Dust from Silver Birch charcoal took up 11·25 per cent. from air saturated at 17° Cent.

A considerable amount of moisture may thus be removed from the air in mine roadways by coal- or stone-dust, when present in fairly large quantity, if the air is very moist, or, conversely, given to it when dry by the evaporation of the adsorbed moisture from the dust.

Table IV.—The Adsorption of Sulphur Dioxide by 100 Grammes of Coal-dust at 30° Cent.

Experimental results.				Figures from curves.		
Dried.		Moist (H_2O=9 per cent).		Dried.		Moist.
Pressure.	Adsorption.	Pressure.	Adsorption.	Pressure.	Adsorption.	Adsorption.
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres at N.T.P.	Cubic centimetres at N.T.P.
0·015	763	0 022	111	0 02	900	70-75
0·052	1,506	0·10	316	0·05	1,490	160
0·283	2,852	0·204	628	0·10	1,965	317
—	—	0·376	1,150	0·20	2,530	630
—	—	0·556	1,575	0·40	3,250	1,230
0·745	3,980	0·751	2,170	—	—	—
—	—	0·852	2,420	0·80	4,070	2,280

Table IV. shows the adsorption of sulphur dioxide by coal-dust (1) dried to contain approximately 1 per cent. of moisture and (2) with a moisture-content of 9 per cent. It will be observed that the shape of this curve (Fig. 3, Plate III.) for the dried material is very different from that of the moist sample, the moisture producing a very marked inhibitory effect, which is especially pronounced at low gas-pressures. The curve for the dry material is typical for the more highly adsorbed gases, a very much greater adsorption taking place proportionally at low pressures than at high.

Attempts were made to measure the adsorption of a higher hydrocarbon of the methane series, and for this purpose normal pentane (C_5H_{12}) vapour was employed. In this case modifications had to be made in the method of introducing a known volume of the vapour. This was carried out by measuring the latter under reduced pressure and admitting it to the flask at this reduced pressure, which was well below the vapour pressure of the liquid at the temperature of the air during the experiment.

The rate of absorption of the pentane vapour was found to be very slow—for example, on adding sufficient vapour to the flask to produce a pressure change of 24 millimetres, after seven days slow adsorption was still taking place at the rate of 3 cubic centimetres per day per 100 grammes of dust. The results given below must, therefore, be considered as rather on the low side :—

Pressure of pentane. Atmospheres.	Per cent.	Adsorption per 100 grammes of coal-dust at 30° Cent. Cubic centimetres at N.T.P.
0·03 =	3·0	160
0·17 =	17·0	450
0·32 =	32·0	750

These figures show how the pentane vapour is picked up when present in small concentrations to a very much greater extent than is the case with methane. This fact, combined with the slow rate at which this compound is adsorbed, explains why on pumping out the gases from coal the last traces of the gas are usually very rich in higher hydrocarbons.

The Adsorption of Gases under high Pressures.—The apparatus employed in these experiments consisted of a 1-inch (external) stout-walled glass tube about 8 inches long, closed at one end, whilst the other was sealed to a capillary connecting tube. This latter led by means of a three-way connexion to (*a*) a specially-designed mercury-gauge, and (*b*) to a brass screw-valve. In order to ensure reliable connexion between the glass tubing and the brass valve, the following method was resorted to and found to give a connexion capable of standing high pressures without any trace of leakage :—A piece of glass capillary tubing from 6 inches upwards in length was passed through an india-rubber bung of approximately $\frac{1}{2}$-inch diameter at its narrow end; a small flange was then blown in the end of the tubing—of sufficient over-all diameter to just fit into a $\frac{1}{2}$-inch diameter socket at one end of the brass valve connecting-piece. A small leather washer was placed between the glass flange and the inner face of this socket, the rubber bung moved along the tube into the socket, a metal washer slipped over the tube against the rubber bung, and finally a hexagon screw-cap (through the end of which a hole had been drilled to take the glass tubing) was well screwed on to the valve connecting-piece by means of an external thread on the latter. The other end of the glass capillary tubing could then be sealed wherever necessary. A similar glass-brass connexion was made on the other side of the brass valve and leading to the cylinder containing the gas under high pressure (carbon dioxide, methane, or nitrogen, as the case might be). A T-piece was introduced into this connexion for the purpose of exhausting the complete apparatus before charging the coal with gas under high pressure. Considerable trouble was at first experienced in making a glass gauge which would stand a pressure of 40 atmospheres, but eventually success in this respect was achieved.

This high-pressure gauge was made, consisting of a U-tube, one limb, connecting to the absorption tube containing coal, being approximately 3 feet long, and the other, which formed the gauge proper, about 4 feet long. This piece was made from the lower graduated portion of a Haldane large gas-analysis burette, sealed just above the top graduation mark to (approximately) 16 inches length of capillary tubing. The volume of this tube was accurately measured from the top graduation mark on the Haldane tube to the point on the capillary tubing at which it was sealed, and also to a position on the capillary tubing (approximately 14 inches above this) where the tubing was subsequently sealed off. The even bore of the capillary tube was tested and the volume per unit

length estimated. About 12 inches above the bend in the U-tube, and on the other limb, a piece of wider bore tubing had been sealed in to act as a small reservoir for the mercury which was introduced into the U-tube. The upper portion of the graduated limb was now alternately filled and evacuated with dry hydrogen until the pure gas was contained therein. When at atmospheric pressure, the capillary tube was carefully sealed off at the point already referred to. The capillary extension on the Haldane tube made possible a more accurate pressure measurement at high pressures than would have been the case with the larger bore tube alone. Dry hydrogen was used in the pressure-gauge. The gauge was accurately checked against the barometer for atmospheric pressure, and knowing the volume of the gas at any position of the mercury, and the temperature of the surrounding air, the actual pressure could be readily calculated, allowance being made for the deviation from Boyle's Law of the hydrogen in the gauge. A weighed amount of 200-mesh coal-dust was placed in the wide tube sealed at one end, a short length of $\frac{1}{4}$-inch tubing having been sealed to the other end, and a plug of glass-wool introduced into the latter, which was then sealed to the capillary tubing connecting to the gauge, etc. The wide tube containing coal-dust was immersed in a constant-temperature bath working at 10·8° Cent.

The connecting-tubing between the valve and the cylinder was fitted with a T-piece, and through this it was possible to exhaust completely the gas from the apparatus and its connexions.

After exhaustion, the gas was allowed to escape from the cylinder into the apparatus until a pressure of a couple of atmospheres was reached. The gaseous contents were then pumped out and gas again admitted; this operation was repeated a couple of times, the apparatus being finally pumped out to a pressure of about 40 millimetres of mercury. The T-piece connexion to the pump was then sealed off by means of the blowpipe flame. The apparatus was next slowly and carefully charged up to the full pressure in the gas cylinder, which in the case of methane was about 35 atmospheres. The valve was then closed completely. The total volume of apparatus to valve-connexions had been previously determined, as well as the volume of the connexions outside the constant-temperature bath, when the mercury in the gauge was at atmospheric pressure.

As the volume occupied by the coal and small piece of glass-wool was known, the "dead space" in the apparatus and connexions could be calculated. This varied with the pressure, since mercury was forced with increasing pressure from the limb of the U-tube gauge, connected to the apparatus, to the graduated limb.

After about six hours, the pressure reading being constant, the sealed end of the T-piece on the connexion between the valve and the cylinder was broken off, and this tube connected to a 50-cubic-centimetre graduated burette containing mercury. After carefully noting the volume of compressed hydrogen in the gauge-tube and the difference of level in mercury columns in the two limbs of the U-tube, as well as the air-temperature, eight or nine lots of approximately 50 cubic centimetres each were released and collected in the burette and accurately measured there, the air-temperature and pressure being noted.

The first 50 cubic centimetres released was analysed for methane content, and likewise the last. The mean result combined with the total amount released gave the quantity of methane blown off. The analysis of the first sample blown off—combined with the total pressure—gave the actual pressure of methane over the coal-dust with which the methane adsorbed in the coal-dust was in equilibrium.

Sixteen hours were then allowed to elapse before a second "blowing off," and measurements were again made. This process was then repeated, until the pressure was very nearly atmospheric.

The adsorption of methane at this lowest pressure was determined independently on some of the same dust sample by the usual method employed for pressures up to 1 atmosphere. From this and the total amount of gas blown off the results given in Table V. have been obtained. The method of calculating the quantity of gas adsorbed at the different equilibrium pressures will be clear from a study of this table.

TABLE V.—THE ADSORPTION OF METHANE BY 200-MESH DRIED COAL-DUST UNDER HIGH PRESSURES AT 10·8° CENT.

Moisture = 1·23 per cent.

Weight of dried dust, 20·7 grammes.

Specific gravity of dust, 1·315 ∴ volume = 15·72 cubic centimetres.

Volume of coal and glass-wool = 15·73.

Volume of dead space = 45·62 cubic centimetres, when pressure equalled 1 atmosphere.

Volume of dead space immersed = 41·63 cubic centimetres, when pressure equalled 1 atmosphere

Volume of CH_4 present at 10·8° Cent. and 760 mm.	Total pressure.	Percentage of CH_4 over coal.	Volume of dead space out of bath.	Volume of CH_4 calculated from pressure and percentage of CH_4.	Adsorption per 20·7 grammes at 10·8° Cent. and 760 mm.	Adsorption per 100 grammes measured at 0° Cent. and 760 mm.	Pressure of CH_4.
Cubic centimeters.	Atmospheres.	Per cent.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Atmospheres.
117·06	1·230	94·1	4·51	53·36	63·7	296	1·157
503·4	6·761	89	9·893	309·95	198·5	922·5	6·017
872·6	12·78	88·5	10·51	597·2	275·4	1,280	11·28
1,273·7	19·92	87·7	10·74	936·7	337	1,566	17·47
1,623·3	26·15	85·5	10·84	1,220·1	403·2	1,874	22·36
2,119 0	34·93	85	10·91	1,649·8	470	2,184	29·69

Similar experiments were carried out with carbon dioxide and nitrogen. The results of these are given in Tables VI. and VII. respectively. The adsorption under high pressures by *moist* coal-dust (200 mesh) was then measured by employing the same apparatus and method—the same gases, methane, carbon dioxide, and nitrogen, again being used. The results in every case have been corrected for the deviation from Boyle's Law of the gas employed.

The experimental results for these are given in Tables VIII., IX., and X. respectively. The curves for the whole six sets are shown in Fig. 4 (Plate III.). Tables XI. to XIII. give the figures in cubic centimetres of gas at normal (760 millimetres) pressure and 0° Cent., taken from the curves shown on Fig. 4, and also the equivalent amounts expressed in tons per cubic foot.

In one of my previous papers* I gave a comparison of the respective quantities of methane taken up by coal in lumps and in a fine powder, and showed that approximately 70 per cent. of the amount adsorbed by dust of 90-mesh fineness was taken up by lumps of size equal to 0·6 cubic inch. The difference in amounts adsorbed by 90- and 200-mesh dust

* *Trans. Inst. M. E.*, 1919-1920, vol. lviii., page 37.

respectively has been found to be inappreciable. The process of breaking up the coal in the laboratory does not, therefore, produce an increase in the adsorptive capacity of the material at all proportionate to the increase of surface area as calculated from the number of particles into which the larger lumps have been broken. In other words, the actual surface area, as calculated from external dimensions of the particle or lump, forms a small proportion only of the total surface available for adsorption. Taking the latter to be directly proportional to the total surface area available, a simple calculation from the above results, assuming the coal-particles to be in the form of small cubes, would seem to point to the effective surface area being at least 400 times the value calculated from the external dimensions of the particle.

Table VI.—The Adsorption of Carbon Dioxide by 200-Mesh dried Coal-dust under High Pressures at 10·8° Cent.

Moisture = 1·23 per cent.

Weight of dried dust, 20·7 grammes.

Specific gravity of dust, 1·315 ∴ volume = 15·72 cubic centimetres.

Volume of coal and glass-wool = 15·73.

Volume of dead space = 45·62 cubic centimetres, when pressure equalled 1 atmosphere.

Volume of dead space immersed = 41·63 cubic centimetres, when pressure equalled 1 atmosphere.

Total amount of CO_2 present at 10·8° Cent. and 760 mm.	Total pressure.	Per-centage of CO_2 over coal.	Volume of dead space out of bath.	Volume of CO_2 from pressure and percentage of CO_2.	Adsorption of CO_2 per 20·7 grammes measured at 10·8° Cent. and 760 mm.	Adsorption per 100 grammes measured at 0° Cent. and 760 mm.	Pressure of CO_2.
Cubic centi-metres.	Atmospheres.	Per cent.	Cubic centi-metres.	Cubic centi-metres.	Cubic centi-metres.	Cubic centi-metres.	Atmos-pheres.
274·5	1·165	97·0	4·317	51·89	222·6	1,035	1·13
468·7	2·52	94·85	7·456	118·7	350·0	1,627	2·39
868·2	6·52	93	9·84	327·9	540·3	2,511	6·06
1,269·6	10·89	93	10·39	576·8	692·8	3,220	10·13
1,659·2	15·29	93	10·62	845·3	814·0	3,783	14·22
2,286	22·66	92	10·78	1,319·5	966·5	4,491	20·84
2,930	29·59	90·3	10·87	1,814·0	1,116·0	5,186	26·72

It will be noted that a reduction of 98 per cent. in the external surface has only produced a reduction of 30 per cent. in the adsorption effect, so that from solid coal—where the reduction of external surface area is 100 per cent.—we may take for practical purposes the adsorption of gas to be the same as the lump-coal referred to above, namely, at about 65-70 per cent. of the adsorption which is found with fine dust.

A point to consider, of great practical interest, is what will happen when through earth-movements a portion of a seam is ground to the form of a fine dust. Let us assume a gas-pressure of 30 atmospheres throughout the mass of coal in the seam—a reasonable assumption for a gassy seam newly opened—in the light of the late Sir Lindsay Wood's classical experiments.* The accumulation of fine dust previously saturated in the solid and compact condition is now capable of picking

* "Experiments showing the Pressure of Gas in the Solid Coal," *Trans. N. E. Inst.*, 1880-1881, vol. xxx., page 163.

up considerably more gas in order that it may be saturated at the same pressure. This will without doubt take place, gas flowing from the solid until an equilibrium pressure is obtained. With coal such as Barnsley Soft, containing its natural moisture, reference to the tables shows that 1 ton of fine dust will contain as much as 470 cubic feet (or 17 times its volume) of methane. This is obviously not as much as would be contained in a cavity at this pressure. At pressures below 5 atmospheres, however, owing to the shape of the adsorption curve an amount may be taken up by the coal greater than it would be possible to compress into a cavity at the same pressure.

TABLE VII.—THE ADSORPTION OF NITROGEN BY 200-MESH DRIED COAL-DUST UNDER HIGH PRESSURES AT 30° CENT.

Moisture = 1·23 per cent.

Weight of dried dust, 20·7 grammes.

Specific gravity of dust, 1·315 ∴ volume = 15·72 cubic centimetres.

Volume of coal and glass-wool = 15·73.

Volume of dead space = 45·62 cubic centimetres, when pressure equalled 1 atmosphere.

Volume of dead space immersed = 41·63 cubic centimetres, when pressure equalled 1 atmosphere.

Total amount of N_2 added at 10·8° Cent. and 760 mm.	Total pressure in apparatus.	Percentage of N_2 over coal.	Volume of dead space out of bath.	Volume of N_2 from pressure and percentage of N_2.	Adsorption of N_2 per 20·7 grammes measured at 10·8° Cent. and 760 mm.	Adsorption per 100 grammes measured at 0° Cent. and 760 mm.	Pressure of N_2.
Cubic centimetres.	Atmospheres.	Per cent	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Atmospheres.
62·01	1·07	99·3	4·082	48·48	13·53	63	1·06
293·4	4·62	99·3	9·213	233·0	60·4	280·6	4·585
694·3	11·08	99·3	10·41	575·2	119·1	553·5	11·00
992·1	16·08	99·2	10·64	840·4	151·7	705·0	15·95
1,424	23·86	99·0	10·80	1,252	172	798·0	23·62
1,935	33·06	98·0	10·90	1,730	205	952·8	32·40

There will thus be an enormous reservoir of gas available for discharge in the event of the pressure being suddenly released. This might take place, for example, by coal intermediate between the position of the dust accumulation and the working-face being taken off until what is left is insufficient to withstand the high pressure behind it, and is consequently blown out. In his paper* recently read before this Institution, dealing with sudden outbursts of gas in underground workings, Prof. Henry Briggs supported the theory that these unpleasant occurrences are due to the presence of large accumulations of coal, ground to fine powder by earth-movements, containing methane adsorbed in large quantities under considerable pressure, and described his experiments on the adsorption of carbon dioxide and methane by a sample of coal-dust from the recent Ponthenry outburst. The enormous mass of fine dust which is found to accompany the serious outbursts to which Prof. Briggs has referred in his paper easily accounts for the tremendous quantity of gas liberated. Comparison with the figures obtained by Prof. Briggs will show that on the whole my results for Barnsley Soft Coal

* "Characteristics of Outbursts of Gas in Mines," *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 119.

give a rather greater adsorptive capacity for methane and carbon dioxide than shown by Dr. Briggs is the case for the samples from the Ponthenry outburst. I have carried out some adsorption tests on a sample of coal from the Pumpquart Seam, Ponthenry, handed to me by Dr. J. S. Haldane. The results which I obtained for the adsorption of carbon dioxide at a temperature of 17° Cent. in the case of 200-mesh dust (undried) with a moisture-content of 1·8 per cent. were as follows :—

Pressure. Atmospheres.	Adsorption. Cubic centimetres per 100 grammes.	Cubic feet per ton.
0·085	350	125
0·225	670	240
0·67	1,210	434
1·00*	1,500	540

* Extrapolated.

Small lumps of the same coal were also tested. These lumps were on the average between 3 and 4 cubic centimetres in volume, and contained 1·9 per cent. of moisture. The adsorption of carbon dioxide was, of course, at a slower rate than in the case of fine dust, but after 15 days the lumps of coal appeared to be saturated at the existing pressure, which equalled 0·24 of an atmosphere. The adsorption then amounted to 68 per cent. of that taken up by 200-mesh dust from the same sample. Reference to Table VI. for dried Barnsley Softs shows that about the same amount of carbon dioxide has been adsorbed by this dust at a pressure of 0·67 atmosphere as by Barnsley Softs at double the pressure. This coal appears, then, in the natural state to have a much higher adsorptive capacity than is the case with Barnsley coal even when the latter has been artificially dried.

Table VIII.—The adsorption of Methane by 200-Mesh moist Coal-dust under High Pressures at 10·8° Cent.

Moisture = 10·3 per cent.

Weight of dust, 22·973 grammes.

Specific gravity of dust, 1·305 ; ∴ volume = 17·61 cubic centimetres.

Weight of glass-wool, 0·12 grammes; volume of glass-wool, 0·04 cubic centimetres.

Volume of apparatus empty, 61·35 cubic centimetres.

Volume of coal, etc., 17·65 cubic centimetres.

Volume of dead space, 43·70 cubic centimetres.

Volume immersed, 39·7 cubic centimetres.

Volume not immersed, 4·0 cubic centimetres.

When pressure equalled 1 atmosphere.

Total amount of CH_4 at 10·8° Cent and 760 mm.	Total pressure.	Percentage of CH_4 over coal.	Volume of dead space out of bath	Volume of CH_4 from pressure and percentage of CH_4.	Adsorption of CH_4 per 22·97 grammes at 10·8° Cent. and 760 mm.	Adsorption per 100 grammes measured at 0° Cent. and 760 mm.	Pressure of CH_4
Cubic centimetres.	Atmospheres.	Per cent.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Atmospheres.
79·98	1·268	89	4·66	50·04	29·94	98	1·128
383·6	6·630	90	9·88	296·1	87·5	366·4	5·967
830·5	15·10	85·1	10·51	656·5	174	728·6	12·85
1,335	24·48	87·5	10·71	1,119	216	904·6	21·42
1,780	33	84·5	10·80	1,481	299	1,253	28·0

TABLE IX.—THE ADSORPTION OF CARBON DIOXIDE BY 200-MESH MOIST COAL-DUST UNDER HIGH PRESSURES AT 10·8° CENT.

Moisture = 10·3 per cent.

Weight of dust, 22·973 grammes.

Specific gravity of dust, 1·305 ; ∴ volume = 17·61 cubic centimetres.

Weight of glass-wool, 0·12 grammes ; volume of glass-wool, 0·04 cubic centimetres.

Volume of apparatus empty, 61·35 cubic centimetres.
Volume of coal, etc., 17·65 cubic centimetres.
Volume of dead space, 43·70 cubic centimetres.
Volume immersed, 39·7 cubic centimetres.
Volume not immersed, 4·0 cubic centimetres.

} When pressure equalled 1 atmosphere.

Total amount of CO_2 at 10·8° Cent. and 760 mm.	Total pressure.	Percentage of CO_2 over coal.	Volume of dead space out of bath.	Volume of CO_2 from pressure, etc.	Adsorption of CO_2 per 22·97 grammes at 10·8° Cent. and 760 mm.	Adsorption per 100 grammes at 0° Cent. and 760 mm.	Pressure of CO_2.
Cubic centimetres	Atmospheres.	Per cent.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Atmospheres.
143·3	1·055	98·5	4·08	45·38	97·9	410	1·039
268·4	2·282	97·7	7·03	105·12	163·3	684	2·229
562·0	5·753	97·0	9·62	286·4	275·6	1,154	5·58
1,050	12·39	93·5	10·47	643·6	406·4	1,702	11·58
1,591	19·43	96	10·71	1,060·0	531	2,224	18·65
2,763·5	33·34	94	10·89	2,084·0	679·5	2,845	31·33

TABLE X.—THE ADSORPTION OF NITROGEN BY 200-MESH MOIST COAL-DUST UNDER HIGH PRESSURES AT 10·8° CENT.

Moisture = 10·3 per cent.

Weight of dust, 22·973 grammes.

Specific gravity of dust, 1·305 ; ∴ volume = 17·61 cubic centimetres.

Weight of glass-wool, 0·12 grammes ; volume of glass-wool, 0·04 cubic centimetres.

Volume of apparatus empty, 61·35 cubic centimetres.
Volume of coal, etc., 17·65 cubic centimetres.
Volume of dead space, 43·70 cubic centimetres.
Volume immersed, 39·7 cubic centimetres.
Volume not immersed, 4·0 cubic centimetres.

} When pressure equalled 1 atmosphere.

Total amount of N_2 present at 10·8° Cent. and 760 mm.	Total pressure.	Percentage of N_2 present over coal.	Volume of dead space out of bath.	Volume of N_2 from pressure.	Adsorption of N_2 per 22·97 grammes at 10·8° Cent and 760 mm.	Adsorption per 100 grammes at 0° Cent. and 760 mm.	Pressure of N_2.
Cubic centimetres.	Atmospheres	Per cent.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.	Atmospheres.
51·9	1·075	99·8	4·13	47·02	4·88	20·4	1·073
221·7	4·222	99·5	9·03	204·95	16·75	70·15	4·201
567·8	10·68	99·5	10·37	535·0	32·8	137·4	10·62
813·8	15·29	99·5	10·57	770·2	43·6	182·6	15·21
1,206·8	22·73	99·0	10·78	1,151·5	55·3	231·6	22·50
1,718·5	33·06	98·3	10·88	1,636	82·5	345·5	32·5

TABLE XI.—THE ADSORPTION OF METHANE UNDER HIGH PRESSURES BY 200-MESH COAL-DUST AT 10·8° CENT.

FIGURES TAKEN FROM CURVES SHOWN ON FIG. 4 (PLATE III.).

Pressure, in atmospheres.	Dried dust.		Moist dust.	
	Cubic centimetres per 100 grammes.	Cubic feet per ton.	Cubic centimetres per 100 grammes.	Cubic feet per ton.
1	260	93	90	32·3
2	430	154	160	57·4
5	820	294	340	122
10	1,200	431	600	215
20	1,730	621	1,000	359
30	2,200	789	1,310	470

TABLE XII.—THE ADSORPTION OF CARBON DIOXIDE UNDER HIGH PRESSURES BY 200-MESH COAL-DUST AT 10·8° CENT.

FIGURES TAKEN FROM CURVES SHOWN ON FIG. 4 (PLATE III.).

Pressure, in atmospheres.	Dried dust.		Moist dust.	
	Cubic centimetres per 100 grammes.	Cubic feet per ton.	Cubic centimetres per 100 grammes.	Cubic feet per ton.
1	950	341	390	140
2	1,480	531	630	226
5	2,280	818	1,080	387
10	3,190	1,145	1,600	574
20	4,440	1,593	2,310	829
30	5,480	1,966	2,800	1,005

TABLE XIII.—THE ADSORPTION OF NITROGEN UNDER HIGH PRESSURES BY 200-MESH COAL-DUST AT 10·8° CENT.

FIGURES TAKEN FROM CURVES SHOWN ON FIG. 4 (PLATE III.).

Pressure, in atmospheres.	Dried dust		Moist dust.	
	Cubic centimetres per 100 grammes.	Cubic feet per ton.	Cubic centimetres per 100 grammes.	Cubic feet per ton.
1	58	20·8	20	7·2
2	125	44·8	40	14·3
5	310	111	81	29·1
10	520	186	140	50·4
20	800	288	235	84
30	915	329	315	113

At first glance it would appear that there is considerable difference between Prof. Briggs's results for Ponthenry coal and mine for Barnsley coal.

Prof. Briggs's results (*loc. cit.*) apparently give, not the total amount of gas adsorbed by the coal, but the quantities adsorbed at pressures over and above atmospheric, no figure being given for the amount of gas taken up at a pressure of 1 atmosphere. From the point of view of the evolution of gas when the pressure over the coal is dropped from a high pressure to atmospheric, doubtless Prof. Briggs's curves express what will happen; but they do not give the absolute amount of gas adsorbed. If in my tables one substracts the amount of gas absorbed at 1 atmosphere from that at 2, the difference corresponds to the adsorption at 1 atmosphere gauge pressure on Prof. Briggs's curves. To take a concrete example: the adsorption of methane at 2 atmospheres by Barnsley Soft coal, with a moisture-content of 10·3 per cent., a figure slightly greater than that frequently occurring in the freshly-won coal, is 57·4 cubic feet per ton of coal, and that at 1 atmosphere pressure is 32·3; the difference corresponding to an increase of 1 atmosphere pressure equals 25·1 cubic feet of methane per ton, or just under 1 cubic foot per cubic foot of coal. This, it will be seen, is about the value Prof. Briggs obtains for his "normal coal." With dried coal, however, I obtained a figure —calculated in the same way—of 61 cubic feet per ton (or 2·3 cubic feet per cubic foot of coal) for an increase of pressure of 1 atmosphere (from 1 to 2 atmospheres absolute pressure). Again, at 10 atmospheres pressure for moist coal my figure came out 215·3 cubic feet per ton, or 182 cubic feet of gas adsorbed per ton between 1 atmosphere and 10 atmospheres absolute pressure.

This equals 6·7 cubic feet per cubic foot of coal, whilst Prof. Briggs's results for 9 atmospheres pressure for "normal coal," taken from his curve, is practically the same.

Comparing the results for carbon dioxide, my results for the adsorption of this gas by Barnsley Soft coal in the moist condition are much of the same order as those found by Prof. Briggs for the *outburst* coal; whilst my figures for the dried material are considerably higher than those given by him.

Although I have not been able to carry out experiments at high pressures with the Ponthenry coal, from analogy with my other experiments it would seem that the normal sample of Ponthenry coal passed on to me should absorb considerably more gas at high pressures than those tested by Dr. Briggs.

The material used in the latter's experiments was apparently considerably coarser than 200 mesh, and I think that possibly a larger amount of gas would have been evolved per unit change of pressure if longer time had been allowed to elapse between the successive readings. In my experiments with 200-mesh dust I found it advisable to leave from four to six hours between the time of releasing the gas at high pressures and taking the final gauge-reading at any one pressure, whilst with coarser coal a still longer time would be advisable in order to ensure complete equilibrium between the gas over the coal and that absorbed in the latter.

In the discussion on Dr. Briggs's paper Prof. Haldane referred to an experiment which I was then carrying out at his (Prof. Haldane's) suggestion. This was with the object of ascertaining whether this softened coal in lump form, when thoroughly charged with gas at high pressures, would, on suddenly releasing the pressure, fly into fine dust on

account of the tremendous pressure inside the lumps. In order to ascertain this, a $\frac{1}{4}$-pound of the Pumpquart Seam sample was placed in a stout metal shell, fitted with a washer and a threaded top, to which was screwed a valve with a pressure-gauge and connexion to a cylinder containing compressed carbon dioxide. The coal consisted of small lumps, freed completely from all dust, etc., varying in size from 0·4 to 7 cubic centimetres, the average working out at 2·5 cubic centimetres. A pressure-tight joint having been obtained, the carbon dioxide was turned on from the cylinder, and the apparatus charged up to about 30 atmospheres. The gas-mixture in the shell was then blown off into the air, and the process of charging and release repeated so as to ensure that all air had been expelled from the shell, and that an atmosphere of pure carbon dioxide remained.

The shell was then charged with the carbon dioxide up to a pressure of 35 atmospheres immersed in a water-bath at the laboratory temperature. After 24 hours the pressure was increased to 60 atmospheres, and this pressure was maintained for 26 hours.

The apparatus was then disconnected, the pressure being suddenly released by opening the valve to its full extent, and the pressure dropped to atmospheric in 15 seconds.

Table XIV.—The Adsorption of Methane under High Pressures by 100 Grammes of 200-Mesh Silver Birch Charcoal (dried) at 30° Cent.

Experimental.		Figures from curve.	
Pressure, in atmospheres.	Adsorption, in cubic centimetres.	Pressure, in atmospheres	Adsorption, in cubic centimetres.
1·23	2,230	1	1,950
2·754	3,637	2	3,000
6·01	4,921	5	4,600
12·18	6,216	10	5,910
16·68	6,739	20	6,990
25·43	7,285	—	—

No trace of dust was blown out, and none was found inside the shell. As it was thought a sufficiently long interval might not have been left to allow complete saturation of the coal at this pressure, the experiment was repeated, the coal being subjected to a pressure of over 50 atmospheres of carbon dioxide for 22 days. The pressure was then suddenly released, and dropped to atmospheric in 8 seconds. On opening the shell no trace of dust was found, but the coal continued to give off the dissolved gas for many hours afterwards, just as in the case of the outburst at the Nord d'Alais Colliery.

These experiments proved to us quite conclusively that the coal in lumps highly charged with gas does *not* disintegrate into dust when the external pressure is suddenly diminished. It seems moderately certain, therefore, in the case of those outbursts where large quantities of dust have been blown out that this dust was previously formed through some process of grinding as a result of earth-movements, sealed up by the solid coal, and there charged up with gas to the pressure existing in the surrounding coal.

Referring again to the results of my high-pressure experiments, it will be observed that the effect of moisture on the adsorptive capacity is very evident even at high pressures.

The curves (Fig. 4, Plate III.) show very well that there is considerable deviation from the simple Henry's Law at high pressures, and in the case of the dried samples this is noticeably more marked than with those containing moisture. The adsorption of nitrogen by moist coal up to a pressure of 30 atmospheres approximates more nearly to Henry's Law than was the case in any of the other experiments.

TABLE XV.—ADSORPTION OF SULPHUR DIOXIDE AND HYDROCHLORIC-ACID GAS BY 100 GRAMMES OF 200-MESH SILVER BIRCH CHARCOAL (DRIED).

Experimental.				Figures from curves.		
Sulphur dioxide.		Hydrochloric-acid gas.		Pressure.	Adsorption of sulphur dioxide.	Adsorption of hydrochloric-acid gas.
Pressure.	Adsorption.	Pressure.	Adsorption.			
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Cubic centimetres.
0·013	2,200	0·005	1,150	0·05	4,850	2,920
0·04	4,360	0·025	2,290	0·10	6,500	3,900
0·095	6,440	0·077	3,395	0·20	8,150	5,080
0·21	8,310	0·145	4,450	0·40	9,810	6,600
0·425	9,870	0·23	5,500	0·60	10,650	7,600
0·76	11,060	0·38	6,460	1·00	11,600	8,930
1·23	11,970	0·85	8,420	—	—	—
1·73	12,720	1·00	8,930	1·50	12,400	—

TABLE XVI.—ADSORPTION OF METHANE BY 100 GRAMMES OF SILVER BIRCH CHARCOAL AT 30° CENT.

Experimental results.						Figures from curves.			
2-10 mesh.				200-mesh.		Adsorption.			
Dried (H_2O = 1·38 per cent).		Moist (H_2O = 7·8 per cent).		Dried (H_2O = 0·7 per cent).		Pressure.	2-10 mesh.		200-mesh.
Pressure.	Adsorption.	Pressure.	Adsorption.	Pressure.	Adsorption.		Dried.	Moist.	Dried.
Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Cubic centimetres.	Cubic centimetres.
0·04	159	0·055	94·5	0·035	133	0·05	190	85	190
		0·115	181	0·07	267	0·10	352	162	370
0·18	588	0·175	268	0·18	646	0·20	640	300	680
		0·24	351	0·39	1,089	0·40	1,100	512	1,150
0·36	963	0·31	426	0·55	1,420	0·60	1,437	680	1,490
		0·46	565	0·68	1,594	0·80	1,690	814	1,740
0·74	1,650	0·70	752	—	—	—	—	—	—

TABLE XVII.—ADSORPTION OF METHANE BY CANNEL AND BLACK SHALE AFTER DESTRUCTIVE DISTILLATION IN RETORTS, BOTH SAMPLES STILL CONTAINING CARBON.—DRIED.

Experimental results.				Figures from curve.		
Retort cannel.		Retort shale.		Adsorption.		
Pressure.	Adsorption.	Pressure.	Adsorption.	Pressure.	Retort cannel.	Retort shale.
Atmospheres.	Cubic centimetres	Atmospheres.	Cubic centimetres.	Atmospheres	Cubic centimetres.	Cubic centimetres.
0·077	51·6	0·111	15·8	0·05	35	7·5
0·159	100	0·227	28·7	0·10	65	14
0·256	144	0·34	42·3	0·20	123	27
0·357	186	0·576	62·9	0·40	205	48
0·468	225	0·825	77	0·60	269	64
0·583	262	—	—	0·100*	378*	85*
0·701	299	—	—	—	—	—

* Extrapolated.

The original shale, for 0·84 atmosphere pressure of CH_4, absorbed only 7·3 cubic centimetres per 100 grammes dust.
The completely spent shale, for 0·86 atmosphere pressure of CH_4, absorbed only 6·8 cubic centimetres per 100 grammes dust.
The completely spent and weathered material, for 0·86 atmosphere pressure of CH_4, absorbed only 4·3 cubic centimetres per 100 grammes dust.

TABLE XVIII.—ADSORPTION OF METHANE AND CARBON DIOXIDE BY FINE 200-MESH COCOANUT CHARCOAL (MOISTURE CONTENT = 1·52 PER CENT.).

Experimental results.				Figures from curves.		
Methane.		Carbon dioxide.		Adsorption.		
Pressure.	Adsorption.	Pressure	Adsorption.	Pressure.	Methane.	Carbon dioxide.
Atmospheres	Cubic centimetres.	Atmospheres	Cubic centimeters.	Atmospheres	Cubic centimetres.	Cubic centimetres.
0·047	77	0·091	583	0·05	80	340
0·100	150	0·241	1,127	0·10	150	610
0·208	286	0·457	1,612	0·20	280	1,010
0·345	411	0·737	2,047	0·40	475	1,505
0·557	582	—	—	0·60	625	1,820
0·782	740	—	—	0·80	735	2,130

In Table XIV. is shown the results of an experiment with methane and Silver Birch charcoal (at that time being used in army respirators), the adsorption being measured with gas-pressures up to 25·4 atmospheres. The amount adsorbed at a pressure of 1 atmosphere is nearly eight times that adsorbed at the same pressure by Barnsley Soft coal (dried), even though the temperature of the coal was nearly 20° Cent. higher. The curve drawn from these results is shown on Fig. 5 (Plate III.), where those showing the adsorption of sulphur dioxide and hydrochloric-acid gas by the same material at lower pressures are also given (being taken

from Table XV.). In Table XVI. the influence of the size of the particles of Silver Birch charcoal on the adsorptive capacity will be seen. The 2 to 10-mesh dust when dried absorbs only a slightly less quantity than the 200-mesh dust. From this one may reasonably conclude that in the case of Silver Birch charcoal the surface area of the charcoal, calculated from external measurements, is insignificant compared with the total available surface for adsorption.

In Tables XVII. and XVIII. are given the adsorption results, and on Figs. 7 and 8 (Plate IV.) the curves drawn from these, for several substances, showing the effect of destructive distillation upon such carbonaceous substances in producing a form of carbon in the material with a high " internal " surface area.

In Fig. 7 is shown the adsorptive curve for carbon monoxide by fine coal-dust. This is introduced to explain why the ordinary type of army respirator is, practically speaking, of no use against this gas. To illustrate this point, let us consider the adsorption of chlorine by Silver Birch charcoal. I have measured this at low concentration and obtained the results given below. Although the adsorption of carbon monoxide by the same material has not been determined directly, from the results of the adsorption by coal-dust and from a comparison with methane it would appear probable that this gas at similar concentrations would be picked up in the quantities shown below :—

Concentration. Per cent.	Chlorine adsorbed per 100 grammes. Cubic centimetres.	Carbon monoxide adsorbed per 100 grammes. Cubic centimetres.
0·13	1,662	2
0·4	1,719	6
10·0	5,414	–

From these results it is evident that the ordinary charcoal type of respirator, so efficient where chlorine and like gases are concerned, will be comparatively useless for the adsorption of carbon monoxide from atmospheres containing small percentages of this gas.

Below are given some further results obtained with other powdered materials, and these show the extent to which gases will be adsorbed by the dust from such materials :—

Substance.	Adsorption per 100 grammes. Cubic centimetres.	Concentration of gas-mixture. Per cent.
Powdered sand extracted with acid (dried)	31	85 CO_2
,, glass (dried)	11	85 ,,
,, shale (grey)	32	100 ,,
,, ,, (black)	7·3	84·5 CH_4
,, ,, ,, completely burnt and weathered	4·3	85·9 ,,
,, ,, ,, completely burnt, but not weatherod	6·8	86·3 ,,

In the above cases the adsorption was found to be—within the limits of experimental error—directly proportional to the pressure of the gas.

In Table XIX. are given results showing the solubility of carbon dioxide and sulphur dioxide in water at 30° Cent., the corresponding curves being given on Fig. 9 (Plate IV.). From the latter it will be seen that carbon dioxide follows Henry's Law, whilst the more soluble sulphur dioxide shows a slight deviation from this.

A comparison of the shape of the curves on Figs. 1 to 8 (Plates III. and IV.) shows very clearly that the greater the adsorption or solubility of the gas the more pronounced is the deviation from the simple straight line expressed by Henry's Law of the solubility of gases. Numerous investigators have attempted to express mathematically the quantitative

relationship between the pressure and the adsorption of gases, and the exponential equation $A = c P^n$ has been commonly applied, where A and P are the amount adsorbed and the pressure respectively, and c and n are constants. When $n = 1$, the equation becomes linear—that is, Henry's Law holds. I have attempted to find the value for the constants for the equation when applied to my results, and give below the value for n in cases where the exponential equation held moderately well within the range of pressures at which the tests were carried out:—

	Adsorption of—	by—	Value of n.
(1)	Sulphur dioxide	Dried Silver Birch charcoal	0·28
(2)	Hydrochloric-acid gas	,, ,, ,, ,, ...	0·37
(3)	Carbon dioxide	Dried coal-dust (high-pressure experiment)	0·51
(4)	,, ,,	Moist ,, ,,	0·57
(5)	Methane	Dried ,, ,,	0·61
(6)	,,	Moist ,, ,,	0·68
(7)	Nitrogen	Dried ,, ,,	0·79
(8)	,,	Moist ,, ,,	0·83
(9)	Sulphur dioxide	Water	0·95
(10)	Methane	Dried cocoanut charcoal	0·71
(11)	,,	Dried Silver Birch charcoal	0·71

Schmidt and later Arrhenius* claim that the experimental results for the adsorption by charcoal can be expressed much more accurately by equations which involve the assumption that a "maximum" adsorption occurs, for which the simple exponential equation makes no allowance. According to the latter equation, the adsorption will increase indefinitely with increase of gas-pressure.

Table XIX.—The Solution of Carbon Dioxide and Sulphur Dioxide in Water at 30° Cent.

Experimental results.				Figures from curves.		
Carbon dioxide.		Sulphur dioxide.		Quantity dissolved per 100 grammes water.		
Pressure.	Quantity dissolved per 100 grammes water.	Pressure.	Quantity dissolved per 100 grammes water.	Pressure.	Carbon dioxide.	Sulphur dioxide.
Atmospheres.	Cubic centimetres	Atmospheres	Cubic centimetres.	Atmospheres.	Cubic centimetres.	Cubic centimetres.
0·114	6·4	0·1075	385	0·05	3·4	185
0·213	14·6	0·245	760	0·10	6·7	350
0·428	28·4	0·381	1,130	0·20	13·4	645
0·745	50·0	0·511	1,502	0·40	26·7	1,200
(0·865*	55·7)	0·648†	1,869	0·60	40·2	1,740
0·849†	57·2	0·915	2,605	—	—	—

* After ½ hour. † After 20 hours.

It was with the object of ascertaining whether in the case of gases more highly adsorbed by coal or charcoal it was possible to reach this maximum adsorption that sulphur dioxide and hydrochloric-acid gas were experimented with. In neither of these, however, was I able to obtain a figure which could be described as approaching such a maximum even at the highest concentration or gas-pressure at which

* *Vide* Arrhenius, *Theories of Solutions*.

experiments were carried out; nevertheless, it is very evident from the curves that in the case of highly-adsorbed gases the increase in adsorption at higher pressures is relatively very small compared with that shown at the lower concentrations of gas.

In connexion with the adsorption of methane, a point of practical interest to mining engineers is the thermal change accompanying this phenomenon. During the adsorption of this gas a certain amount of heat is evolved, and conversely when the adsorbed gas is liberated a similar amount of heat will be absorbed. This cooling effect is especially noticeable at a gassy longwall working-face where a considerable amount of firedamp is draining away through breaks and fissures from behind the coal-face.

From preliminary measurements of this heat of adsorption of methane by coal-dust, I have obtained a figure of 0·1 calorie per cubic centimetre, or 28 large calories per cubic foot of gas adsorbed. If we have in the coal-seam a pressure of 10 atmospheres, and during mining the pressure of gas drops to 1 atmosphere, the quantity of gas given off, according to my figures for Barnsley Soft coal (moist), should be 183 cubic feet per ton of coal. If one takes 70 per cent. of this figure as the amount given off from solid coal, the cooling effect of the gas would be such as to produce a lowering of temperature in this mass of coal of 2·1° Fahr. It is thus readily intelligible how the temperature of coal at a longwall-face may be lowered well below the natural rock-temperature when it is being worked at a rate sufficient to counterbalance the heat-flow from the higher temperature of the surrounding strata. Owing to the comparatively low conductivity of coal, shale, etc., it is not surprising to find a difference of 2° to 3° Fahr. between the temperature taken 12 to 15 feet in front of a longwall-face and the natural rock-temperature at the same depth at other points in close proximity to this working-face.

In conclusion, I wish to express my best thanks to Prof. J. S. Haldane for the many fruitful suggestions he has given me during the conduct of this research.

Dr. J. S. Haldane, F.R.S. (Oxford): Perhaps the President would allow the discussion on this paper to be combined with any further discussion on Prof. Henry Briggs's paper,* which deals with the same subject.

The President: I think that a very useful suggestion.

Mr. E. O. Simcock (Bucknall, Staffs.): There is a point on which I would like to have a little information if available. Mr. Graham states that "In connexion with the adsorption of methane, a point of practical interest to mining engineers is the thermal change accompanying this phenomenon. During the adsorption of this gas a certain amount of heat is evolved." It seems to me that if there is an evolution of firedamp from the coal-face, and then a subsequent adsorption of that gas, a certain amount of air will be adsorbed or absorbed along with the methane. I would like to ask Mr. Graham whether he has any results of the analyses of gas after such an adsorption. The point seems to be of some importance to mining engineers and to all actively engaged in underground operations.

It will be remembered that, some three years ago, there was a

* "Characteristics of Outbursts of Gas in Mines," *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 119.

colliery disaster in the North Staffordshire district, the investigation of which concluded rather unsatisfactorily from the point of view of its initiation. During the course of my investigation of that disaster I found that the gas in the particular seam involved was practically at atmospheric pressure, so that the evolution of gas was less or greater than the rate of diffusion, according to slight variations in the atmospheric pressure. Now, is it possible, if adsorption took place under such conditions, that, by catalytic action, some chemical change occurred, causing the formation of some of the higher hydrocarbons, such as ethane, in lieu of the methane? If that were so, the recognition of such a change would help to elucidate a problem which, at present, is not solved, and, incidentally, help to prevent future disasters. It may also explain the thermal change recognized by Mr. Graham.

Dr. J. S. Haldane: During the war, probably members had not very much heart left to give much attention to Mr. Graham's previous paper on two of the properties of coal, first its capacity for dissolving or adsorbing large quantities of gas, and secondly the extraordinary slowness with which gas penetrates solid coal. The two things are both very important, and this paper gives full data as to the capacity of coal for dissolving or adsorbing gases in general. You can see from Mr. Graham's paper that there were two lines running through his work at the time. One was the war line. During the early and middle years of the war, the question of protection against gas became very urgent, and it was necessary to obtain all the information we could as to the property of charcoal and other substances of adsorbing gas. Charcoal, which was used in the respirators, was known already, of course, to be a substance which takes up gas by what is called "adsorption"; but the information on the subject was very patchy, and Mr. Graham undertook a number of experiments on this subject to determine the conditions on which the efficiency of adsorption depended, and also the effect of other substances in preventing an adsorbing substance like coal or charcoal from efficiently taking up gas—for instance, a poisonous gas. It was necessary to understand the whole thing. Mr. Graham did a great deal of work in that direction for the Munitions Inventions Department, and some of that work appears in this paper. It was not published at the time—for very good reasons.

The solubility and relative impermeability of coal to gas are both very important properties. Coal differs from charcoal in this way, that a gas which is adsorbed by it takes a long time to penetrate. If the coal is at all in coarse particles, it takes quite a long time for the gas, whatever it is, to penetrate in or out; and that is in many ways a very fortunate thing for miners. Supposing that coal was not, relatively speaking, so impermeable to gas, and supposing that it was highly charged, the gas would come off at a most inconveniently rapid rate when the coal was first exposed to the air. In the case of actual coal, on the other hand, although the gas is under great pressure inside the coal, yet it comes off gently even with soft coal, as we have seen in these experiments. These experiments show another point. Many physical chemists have drawn a distinction between adsorption and solid solution. They regard adsorption as a condensation on the surface which occurs rapidly, and solid solution as a different process due to the gas gradually getting into the inside of the solid. Well, in the case of coal, evidently you cannot distinguish between the two. Coal has in one sense an enormous internal surface. If you look at it from the molecular point of view, it has a sort of spongy structure, but the

meshes of the sponge are of absolutely ultra-microscopic proportions. It takes a long time for gas to diffuse into the relatively very narrow pores which exist in coal. Gas gets through very slowly, so that a large lump of coal which has lain for many years in a colliery office as a solid lump will have plenty of methane inside that has never got out. It has never had time to get out, and the oxygen has never had time to get inside the coal. It takes a very long time, but the methane by degrees gets away, and the oxygen by slow degrees gets in. Hence at the side of a road where solid coal has been exposed to air for a long time, or in coal waiting for shipment, the inside still contains oxidizable substances ready to heat up whenever crushing lets air in, and ready even to give off a certain amount of gas.

What are these adsorption curves mathematically? Would they, if continued, give a horizontal asymptote? Mr. Graham has got fairly near it with sulphur dioxide and methane in charcoal (Fig. 5), and the curves for these gases are very like rectangular hyperbolas, of which a rational physico-chemical interpretation would be possible. My own impression is that we are not very far from a rational explanation of adsorption or solution in solids, and that it will turn out to be of the same physico-chemical nature as solution in liquids. For the present, however, we are driven to the use of unsatisfactory mathematical expressions with no definite physical meaning. These expressions are only useful for helping us to predict limited portions of the curves.

This paper will be, I think, referred to again and again. We have got on these curves something which people can go back to for the answers to all sorts of questions that are sure to arise in the future. The appearance of papers like this in the *Transactions* gives them a very permanent value, although the paper may seem just at the moment to contain much rather dry detail.

The President (Sir John Cadman, K.C.M.G.): This paper is one that really does not lend itself to discussion. It illustrates, however, the complexity of the problems with which we have to deal. Exactly what may be the outcome of such a piece of research as this no one at the moment can say. The more we know, the more we can find out of the composition of the chemical and physical characteristics of coal, the more certain will be the introduction of methods and processes by which the energy contained in coal may be more effectively used. Mr. Graham is to be congratulated on the volume of work which he has recorded in this paper. He has indicated the adsorptive properties of certain products, including coal. He has indicated that the rate of adsorption of carbon monoxide in charcoal, for instance, is very low, and has explained why it has not been possible to devise a respirator which would adsorb carbon monoxide. This raises a very practical and important question. Every one connected with mining would welcome the introduction of an efficient respirator capable of absorbing carbon monoxide. The paper suggests a line of research, namely, to devise a method of converting carbon monoxide to the more readily absorbable carbon dioxide within the chamber of a respirator.

Mr. A. M. Henshaw (Talke): I feel that we owe an apology to Mr. Graham for the somewhat limited discussion on his paper. But Mr. Graham must not take as the measure of the value of this paper the attitude of the members to-day. Many of us never saw the paper until this afternoon. Some had advance copies, but the subject appeared to

be so formidable that we dared not tackle it. I want Mr. Graham to realize that we put a very high value on the paper: it will be printed in our *Transactions*, and it is a monumental work. It lays down new laws and new figures which are going to be of incalculable help in the future to the members of this Institution. I say these few words so that Mr. Graham may not be discouraged at the short discussion.

Prof. Henry Briggs (Edinburgh) wrote: Information of practical value, especially in connexion with the problems of spontaneous combustion and gas outbursts, has already been obtained from the study of coal as an adsorbent. The results are, indeed, so striking and useful that further contributions to our knowledge of adsorption phenomena are always welcome; especially is this the case when they possess the trustworthiness which we have learnt to associate with Mr. Graham's work. It happens that I have recently been engaged upon the same problem, and I therefore regard Mr. Graham's data with especial appreciation and his conclusions with interest, not untouched, here and there, with shadows of doubt. Our work fuses fairly well; for although Mr. Graham's experience of the adsorption of coal greatly exceeds my own, I have perhaps experimented with a wider range of substances.

These adsorbents are eminently porous bodies. Porosity is not by any means the only characteristic they possess, but it is an essential characteristic. They must be penetrable to gas, or they cannot adsorb it. Yet while Mr. Graham has shown how adsorptive coal is, he has also shown it to be, in the unfissured state, virtually impenetrable to gas.* Can he resolve the difficulty arising out of these apparently contradictory conclusions?

The chief difficulty in carrying out tests on the adsorption of gases in coal is that due to moisture. To what extent ought the material to be dried, and how should the drying, if any, be carried out? From the point of view of the strictly practical applicability of the results the aim should, I think, be to employ the coal in the laboratory in the condition, as to moisture, in which it is found in the mine; but even that aim is not an easy one, for the moisture-content is not constant at all parts of the workings. I am glad to see that Mr. Graham is tackling the moisture problem so pertinaciously. Rather too much stress has been laid in the past on results obtained with coal dried at 105°—110° Cent.; they are interesting for comparative purposes, but they hardly "hit the nail on the head," since in the drying operation the adsorptive power is augmented considerably by the expulsion of combined water. Such tests, therefore, deal with an artificial and not with the natural substance. If we could drive off the adsorbed moisture without disturbing the combined moisture, the problem would take on a new complexion, but this we cannot be sure of doing. Heating to the stated temperature also starts—with some coals, at any rate—a breakdown of certain of the hydrocarbons.

The results which Mr. Graham has obtained when coal or charcoal is permitted to take up a mixed adsorbate, whether of gases, vapours, or moisture and gas (for the problem is really a single one), agree with those of other workers, and the explanation he advances, namely, that the adsorbate most readily dissolved occupies the surface of the solid and thus reduces the extent of surface available to other gases, is generally accepted.

* *Trans. Inst. M. E.*, 1916-1917, vol. lii., page 338.

In regard to the references to my paper on gas outbursts in mines,* Mr. Graham is correct in taking the gas-discharges therein expressed as those occurring when the pressure was released to atmospheric pressure, and not to the absolute zero of pressure. He considers my figures for the gas-capacity, under pressure, of the Ponthenry coal to be too low; I am inclined to regard his as being rather too high, because, as stated above, his process of drying involves a partial activation of the coal. The important point here, however, is that we agree entirely as to the mechanism of these outbursts from the solid.

As Mr. Graham states, the simple exponential formula connecting the amount (a) of gas adsorbed and the pressure (p) at which the adsorption takes place, has commonly been applied; it does not square, however, with the modern view of the process of adsorption, and has been shown to be invalid by Williams,† who derived and tested the following variant for low concentrations of gas:—

$$\text{Log}\,\frac{a}{p} = A_0 - A_1 p,$$

in which A_0 and A_1 are coefficients. In a recent paper on the adsorption of gas under pressure,‡ I was able to show that, with a slight modification, Williams's equation satisfies the experimental results obtained for cocoanut charcoal with nitrogen and hydrogen and for colloidal silica with nitrogen, at pressures up to 100 atmospheres. The modification is needed to account for the gas in the solid which is not adsorbed, but which is under simple compression. For coal and for the gas-pressures found in coal-seams, the latter modification is of little, if any, importance. Henry's Law appears to be a special case in which the coefficient A_1 is negligible.

The only results of which I know in which a gas, at a temperature above its critical temperature, apparently reached a maximum adsorption on the application of pressure are those of Dewar,§ who ascertained the volume of hydrogen taken up by 6·7 grammes of cocoanut charcoal at —185° Cent. He found that charcoal adsorbed a volume which increased from 620 cubic centimetres at atmospheric pressure to 1,050 cubic centimetres at 10 atmospheres, and that between 10 and 25 atmospheres no further gas was taken in. When the gas is at a temperature lower than its critical temperature, however, such a maximum must sooner or later be reached, although it may be masked by the compressibility of the liquid. If Mr. Graham had carried his experiments with carbon dioxide to a pressure above 30 atmospheres, it would have been found that the curve takes another quick bend upwards before settling down on a low gradient. There is an indication of the beginning of a more rapid rise in the last two points of curve I. of Fig. 4 (Plate). It is indeed advisable to limit to gases above their critical temperatures his conclusion that "in the case of highly-adsorbed gases the increase in adsorption at higher pressures is relatively very small compared with that shown at the lower concentrations of gas."

Mr. J. Ivon Graham (Birmingham University): I thank you very much for the kind way in which you have received my paper, because, after all, it must be a very dull one to the average member, and I take it as a great honour that it has been accepted by the Publications

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 119.

† *Procs. Roy. Soc. Edin.*, 1919, vol. xxxix., page 48; *Procs. Roy. Soc.*, A, 1919, vol. xcvi., page 287.

‡ *Procs. Roy. Soc. Edin.*, 1921, vol. xli., page 119.

§ *Procs. Roy. Inst.*, 1906, vol. xviii., page 433.

Committee of the Institution. After Mr. Henshaw's very kind words, I shall certainly not be disheartened, but I felt all along that it was rather too theoretical a paper to bring before the Institution. At the same time, I sincerely hope that it will be of some use to the members.

This subject of the adsorption of gases is a very wide one. One is always coming up against the adsorption effect in one line or another, and one never knows when and how it is going to help one out of one trouble or put one into another.

Referring to Mr. Simcock's remarks with reference to the production of higher hydrocarbons by the catalytic influence of dust from coal in charcoal, this is not what one would expect. Experiments on the oxidation of methane in the absence of catalysts show that not higher hydrocarbons, but an oxidized product such as formaldehyde, is produced; and recent work on the oxidation of hydrocarbons in the presence of catalysts has shown that in the case of methane the main product is formaldehyde. However, one does not like to negative the argument altogether until experiments have been carried out. Anyone who has spent some time in research-work, finds that it is not advisable to prophesy too much as to what will happen and what will not! I think it is a very interesting point of research that Mr. Simcock has suggested, and I hope we shall attack it some time.

Mr. GRAHAM subsequently wrote: Dr. Briggs has referred to some work which I carried out a few years ago, the results of which showed that although the adsorption of methane by solid coal takes place to a very considerable extent, for the saturation of the coal an exceedingly long time is necessary. I also found that the more highly adsorbed the gas, the slower was its rate of passage through a slab of coal. The explanation offered in my paper was that the fissures in the coal are of such small dimensions that the volume occupied by the adsorbed layer of gas in such fissures is appreciable compared with the size of the fissure or capillary through which the gas has to pass, and thus the effective size of the fissures, so far as the penetrating gas is concerned, is considerably reduced.

With reference to the suggestion that coal is partially "activated" by drying at 100° Cent., the expulsion of moisture from the coal certainly shows very clearly that an increased adsorption does occur, but I should not be inclined to term this "activation"—that is, in the generally accepted sense of the term.

In the case of the moist samples, these had not been subjected to any artificial drying process whatever; the moisture-content was that of the natural coal—a slight loss having occurred, perhaps, in some cases through exposure to air.

With regard to the use of the simple exponential equation, I am quite of the opinion that this is only an approximate representation of the truth, and the tabular statement of values for n is only of use in giving an idea of the shape of the curves.

I have not yet attempted to apply Williams's equation to my results, but Dr. Briggs, who has gone into the mathematical side of the question more fully than I have, has shown that Williams's equation for low concentrations of gas is with certain modifications applicable also in the case of high gas-pressures.

With further reference to Mr. Simcock's remarks, the thermal change is, of course, generally recognized as resulting from the adsorption of the gas. The actual measurement of the "heat of adsorption" of methane by coal-dust has, however, not previously been determined, so far as I know.

FIG. 3.—ADSORPTION OF SULPHUR DIOXIDE (SO_2).

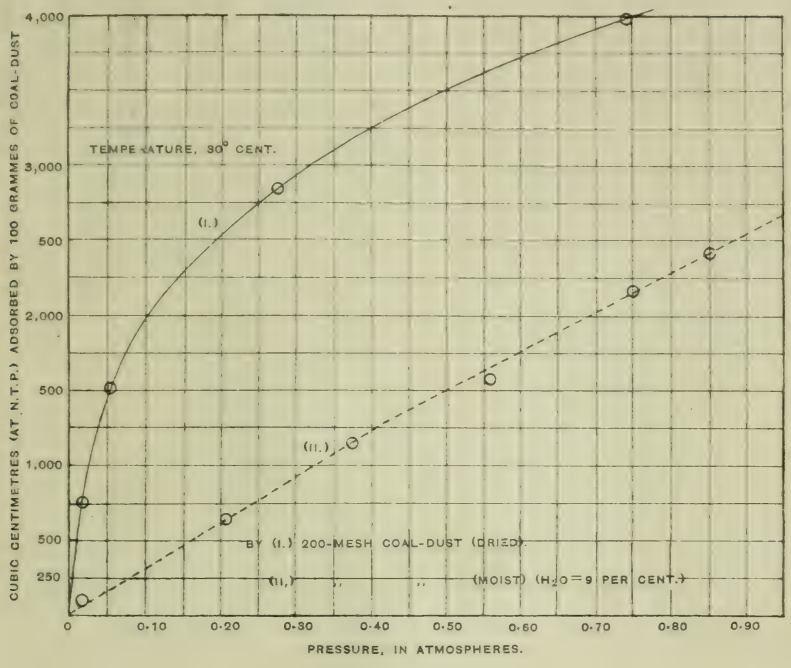


FIG. 6.—ADSORPTION OF METHANE BY SILVER BIRCH CHARCOAL AT 30° CENT.

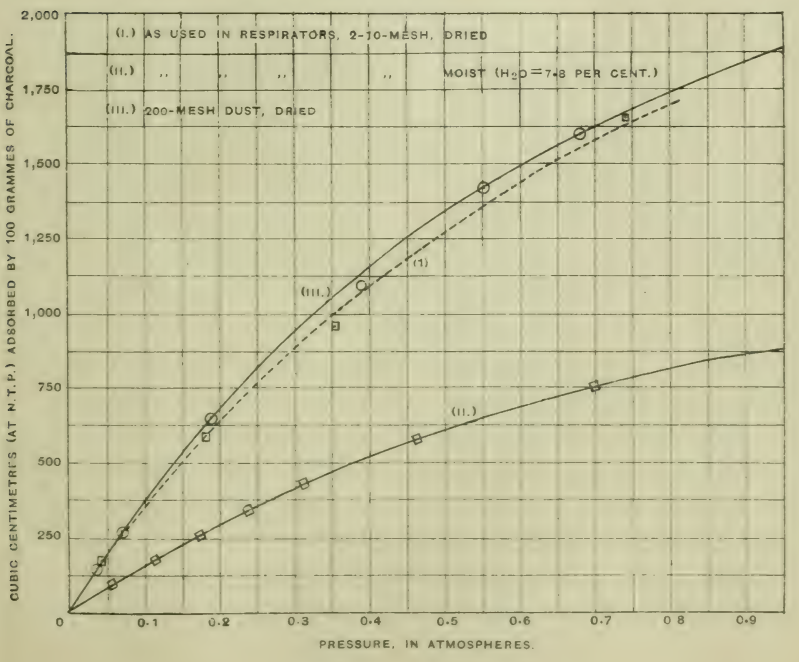


Fig. 1.—Adsorption of Methane (CH_4).

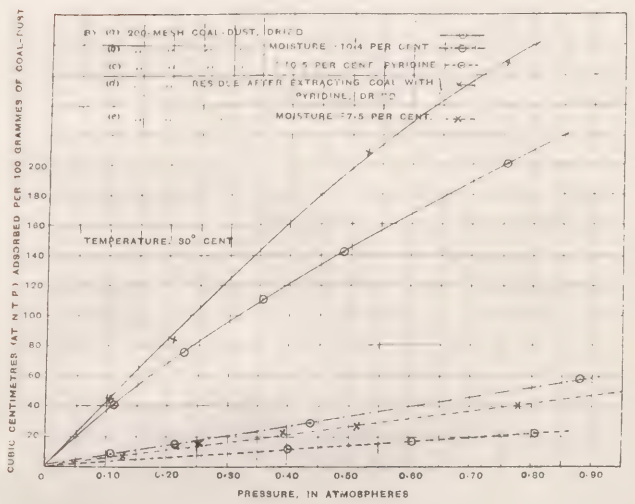


Fig. 2.—The Adsorption of Gaseous Mixtures by Coal-dust, 200-mesh, Dried, Carbon Dioxide (CO_2), and Methane (CH_4).

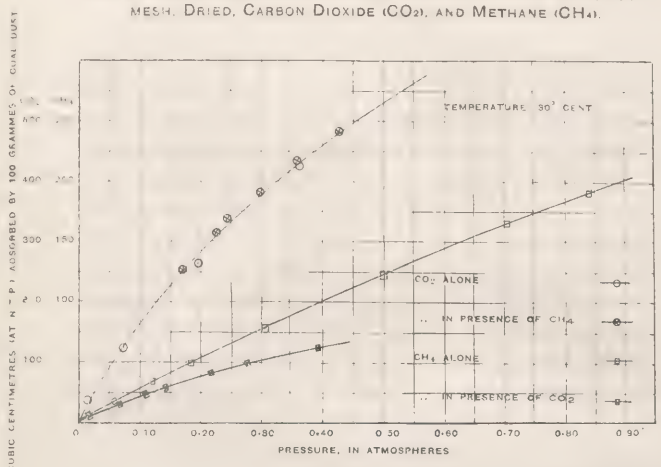


Fig. 3.—Adsorption of Sulphur Dioxide (SO_2).

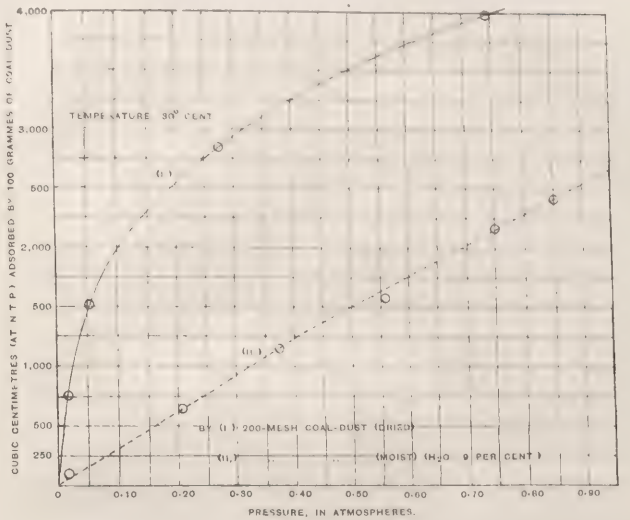


Fig. 4.—Adsorption of Gases under High Pressures by 200-mesh Coal-dust at 10·8° Cent.

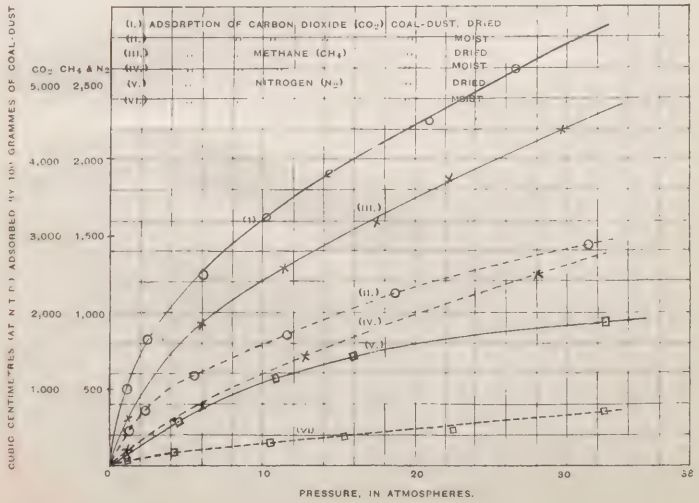


Fig. 5.—Adsorption of Methane, Sulphur Dioxide, and Hydrochloric-Acid Gas by Silver Birch Charcoal.

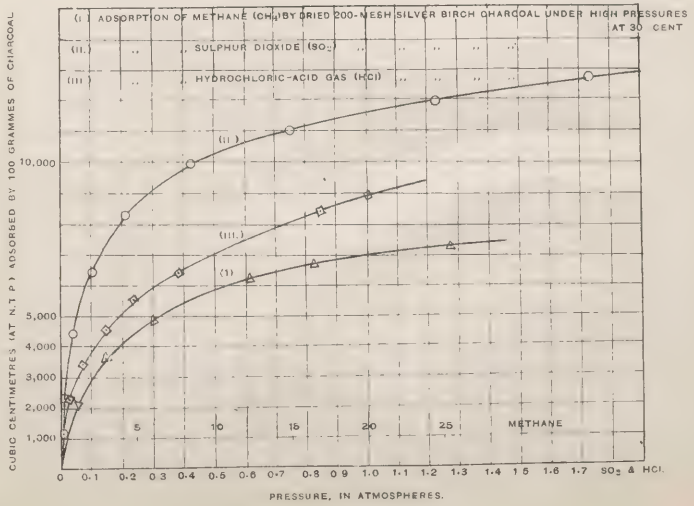
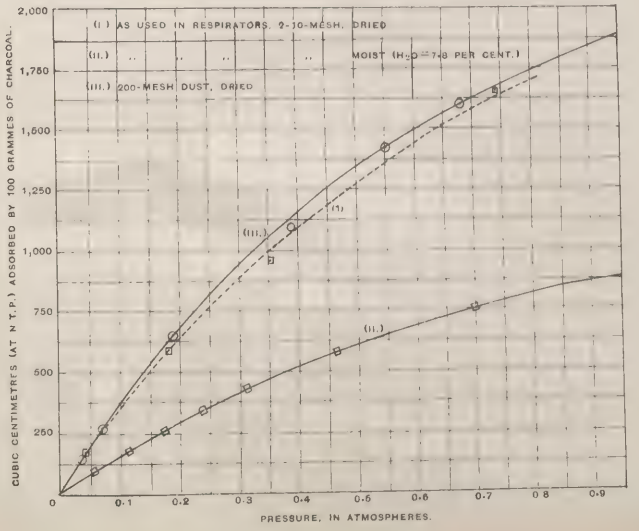
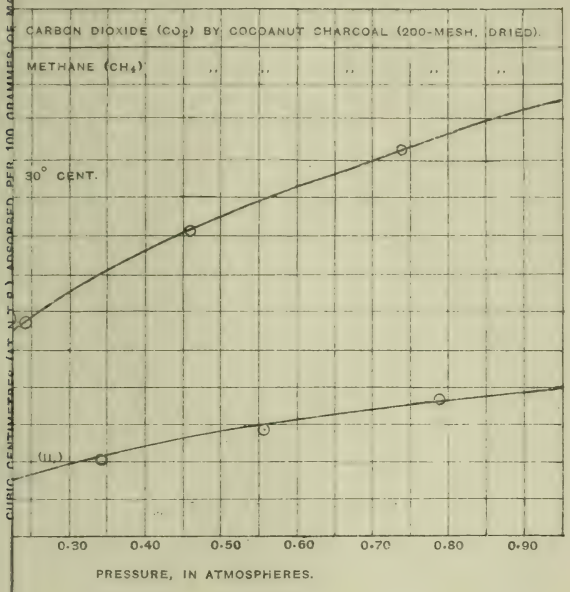


Fig. 6.—Adsorption of Methane by Silver Birch Charcoal at 30° Cent.



Andrew Reid & Comp.ny Newcastle upon Tyne

...SORPTION OF CARBON DIOXIDE AND METHANE.



...DIOXIDE.

To illustrate Mr. J. Ivon Graham's Paper on "The Adsorption or Solution of Methane and other Gases in Coal, Charcoal, and other Materials."

Fig. 7.—Adsorption of Methane and Carbon Monoxide.

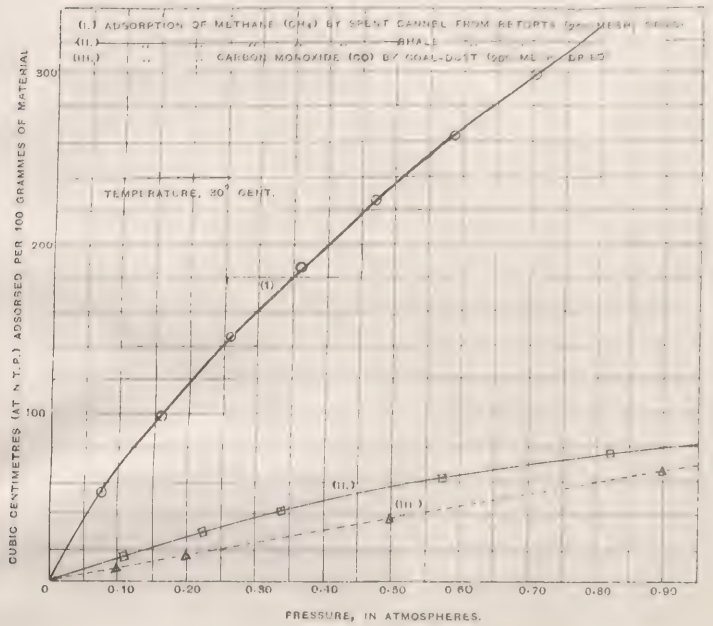


Fig. 8.—Adsorption of Carbon Dioxide and Methane.

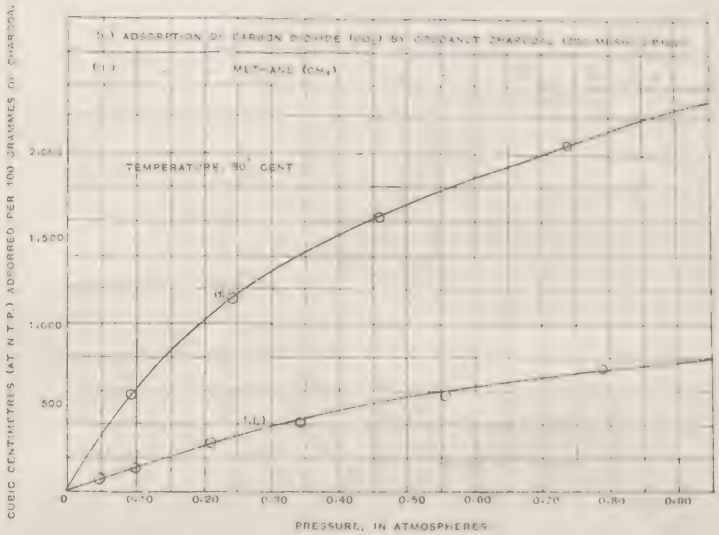
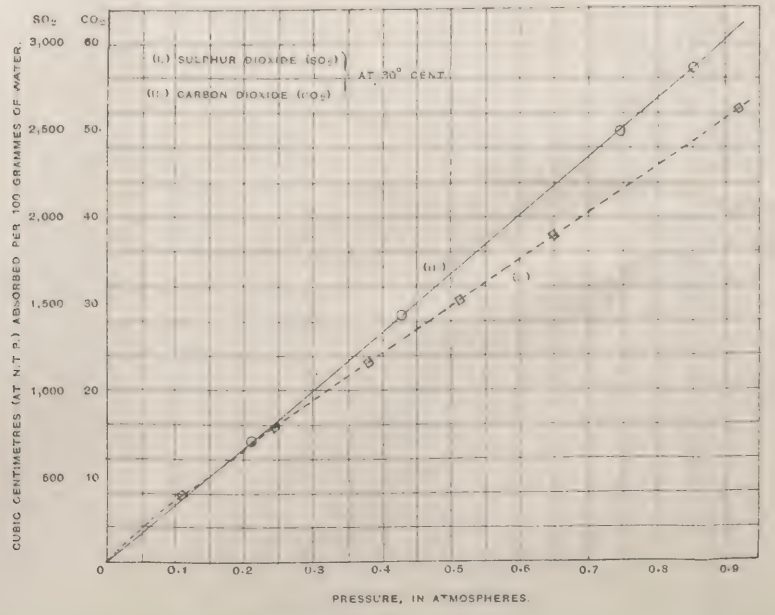


Fig. 9.—Solubility in Water of Sulphur Dioxide and Carbon Dioxide.



Andw. Reid & Compy. Ltd. Newcastle upon Tyne

COAL-MINING BY STEAM-SHOVEL IN ALBERTA, CANADA.

By GEORGE SHEPPARD.

Introduction.—The coal district about to be described occurs in what is known as the Brazeau Forest Reserve in the Foothills west of the Province of Alberta, Canada. The area is roughly 150 miles west of the city of Edmonton, and the Grand Trunk Pacific Railway connects up this city and the east to Vancouver.

In order to develop this comparatively new coalfield of Western Canada, the Alberta coal branch-line of the G.T.P.R. was constructed, which runs from Edson to Coalspur and terminates at the mining settlement of Lovett. The construction of this branch-line has been governed primarily by geological conditions, as it follows a north-westerly to south-easterly direction in conformity with the general strike of the coal-bearing formations. The Little Pembina River flows along the strike of the geological formations of this area, and, as a consequence, is found in close proximity to the railroad.

The major streams or rivers of this district, namely, the MacLeod, Brazeau, and Blackstone, are all probably following pre-Glacial valleys and cut across the strike of the dominant beds, thereby exposing good geologic sections. On account of the enormous volume of water released by the melting of the glaciers in the Rocky Mountains during the summer months of the year, these rivers are gradually entrenching themselves in their pre-Glacial gorges, a fact which is remarkably demonstrated by the presence of river terraces or "benches," which can be seen on either side of the main valley for considerable distances. These terraces demonstrate graphically the different levels of the stream during the earlier part of its entrenching activity.

Topography and Areal Features of the Country.—The chief features of topographical interest are directly connected with geological conditions, and for this reason the territory constituting this part of Western Canada can be subdivided into three groups, namely, the Rockies, the Foothills, and the Plains. The Rockies form the western background, and present an unbroken line of imposing peaks both to the north-west and south-east. Immediately abutting the mountains to the east are minor hills of considerable magnitude, which can be designated the Foothills proper. The Foothills present a series of parallel ridges, with intervening valleys, which give the country a roughly undulating aspect. Towards the east of the above belt, the hills decrease rapidly in altitude, until finally the topography flattens out to the monotonous and gently undulating character of the Plains.

The major part of the area under consideration has been covered with thick forests of spruce, pine, and poplar in the past, but a repetition of forest fires has destroyed the greater part of the older timber. New growth, however, has quickly established itself, with the result that the whole terrain is now supporting a thick growth of new timber which will eventually develop into considerable forest areas.

Geology.—This western part of Canada, and indeed the whole of the same territory extending north and south along the same meridian,

can be divided into three distinct geological and topographical areas, namely :—

(1) The Rockies ... ... Palæozoic.
(2) The Foothills... ... } Cretaceous.
(3) The Plains or Prairies }

As is well known, the Rocky Mountain system stretches from the far north in the Arctic to the southern extremity of New Mexico in an almost unbroken series of parallel mountain-ranges. These huge uplifts or thrust-blocks have been induced primarily by a series of slowly-operating tectonic forces exerted from the Pacific Basin since the close of Cretaceous times.

For the most part the older Palæozoic rocks of the earth's crust, the Carboniferous, Devonian, Silurian, and Cambrian, have been raised into a series of thrust-blocks which, in many cases, have actually overridden the newer Cretaceous formations of the Plains to the east.

At Chief Mountain, in Montana, at the Waterton Lakes Park, and at the Crow's Nest Pass of Southern Alberta, these older rocks of Palæozoic age (usually consisting of hard metamorphosed argillites and limestones) are seen resting upon the newer Cretaceous sediments—a curious reversal of the law of superposition. It is by this process of overthrusting and tectonic compression that the Cretaceous formations have been step-faulted and folded into a series of structural ridges and alternating depressions. Incidentally, it may be noted that the topography of this area directly expresses the underlying geological structure. Towards the east of the Foothills, however, the undulations become less defined, until finally the formations gradually flatten out to approximate horizontality in the Plains.

The general direction of the main range of the Rockies in this part of Alberta is to the north-west, and, as a consequence, the Foothills belt, with its associated features of structural interest, presents the same disposition.

This comparatively small Foothills area which is now being developed for coal near Coalspur extends to the south-east roughly parallel to the Rocky Mountain range. A series of low longitudinal hills and corresponding valleys occur, which are interpreted structurally as anticlines and synclines. Since the original forces operated which caused these undulations in the Cretaceous formations, both glaciation and secondary processes of erosion have modified the topography to an appreciable extent, and, in this way, the crests of the principal anticlinal structures have been eroded and the synclinal valleys deepened.

The most easterly fold of any importance can be termed the Coalspur-Lovett Anticline. To the west of this a corresponding syncline, with minor anticlinal folds and faults, occurs in which the workable seams of coal are available. As will be described later in detail, the most important coal-deposits commercially occur on the crests of the structural uplifts.

In the majority of these cases the coal-operators have little overburden to contend with, owing to the fact that a considerable amount of superficial erosion had taken place prior to the general glaciation. In short, the mining operations resolve themselves into a system of stripping and subsequent removal of the coal by means of the steam shovel.

To the east of the main fold the geological formations flatten out appreciably, and thus the known coal-seams disappear to a considerable depth below the surface of the ground.

A summary of the geological formations occurring in this area is given in Table I. The pre-Cretaceous rocks, however, are found only in the

Rocky Mountain district to the west, whilst of the Cretaceous strata the coal-bearing divisions are the Edmonton, the Belly River, and the Kootenay Formations.

TABLE I.—GEOLOGICAL FORMATIONS.*

			Feet.	
CRETACEOUS.	UPPER.	EDMONTON (Thick)	0	Greenish grey shales, some having claystone concretions, grey to buff sandstone, varying fine to coarse, and conglomerate.
		BELLY RIVER or BRAZEAU (3,000-4,000 feet)	1,000	Similar to Edmonton in upper measures, but lower measures have predominence of light-coloured sandstone, merging into conglomerate, shales, green weathering into small lumps.
			2,000	
			3,000	
		(WAPIABI 600-800 feet)	4,000	Upper dark-grey arenaceous marine shales, containing concretions, with *Scaphites baculites* and *Inocerami*.
		BENTON (1,680-2,400 feet) — BIGHORN (80-100 feet)		Siliceous shaly light-grey and white ripple-marked sandstones, with *Inocerami*.
		BLACKSTONE (1,000-1,800 feet)	5,000	Lower dark-grey and green arenaceous shales. Similar to Wapiabi. Few concretions with shell-fragments found.
		DAKOTA (900-1,600 feet)	6,000	Red and yellow shales, light-grey and white sandstones. Impressions of plant-remains.
	LOWER.	KOOTENAY 1,000-5,000 feet)	7,000	Shaly and siliceous sandstone, black shales, coal-seams, and massive conglomerate, latter 10-50 feet thick top and bottom.
			8,000	
			9,000	
		JURASSIC — Fernie	10,000	Soft dark-grey calcareous shales, with 2-3 feet red limestone near base, abounding in *Belemnites*, *Ammonites*, and *Gryphæa*.
PRE-CRETACEOUS.		TRIASSIC (293 +) — Upper Banff shales	11,000	
		PERMIAN (?) — Rocky Mountain quartzite		
		CARBONIFEROUS — Upper Banff limestone		
		CARBONIFEROUS(?) — Lower Banff shales		
		DEVONIAN (3,250 ±) — Lower Banff limestone		
		DEVONIAN (3,250 ±) — Intermediate beds		

* *Can. Geol. Surv. Memoir*, 9-E.

In the Coalspur Coalfield the workable seams are found in the Belly River formations only, as this strip of territory happens to be folded suitably for the development of the coal-deposits on the surface.

In conformity with the general rule of the Western Provinces of Canada, the first coal was discovered through the efforts of prospectors, who were attracted to the field some twelve years ago.

The original samples were analysed at the provincial laboratory, and proved to be of a high grade. Operating companies then became interested in the field, and large areas were staked for the purpose of subsequent exploitation. At the moment about ten coal companies are working in this district, and the majority are producing a good domestic or a fair-grade steam-coal. The deposits throughout are remarkably uniform in quality, and certain seams produce a good coking material yielding about 75 per cent. of coke.

Table II. gives an idea as to the relative values of the coal produced from the respective mines.

TABLE II.—COMPARISON ANALYSES OF COALS.

Name of coal.	Moisture.	Ash.	Volatile matter.	Fixed carbon.	Calorific Value.	Method of mining.
	Per cent.	Per cent.	Per cent.	Per cent.	B.Th.Us.	
Yellow Head, Mile 37...	3·7	11·4	33·2	51·7	11,400	Usual
Mine at Mile 33 ...	7·02	6·70	39·72	46·56	11,310	,,
Foothills, Mile 50 ...	7·85	5·57	37·18	49·40	11,290	,,
Pacific Pass Company, Mile 57	4·9	12·7	36·7	45·7	11,220	,,
Oliphant-Munson, Mile 47	7·30	7·82	39·98	46·90	11,140	Stripping lower bench
Do.	8·39	29·32	29·20	33·09		Stripping top bench
Blackstone Coal, Limited, Mile 52½ ...	6·6	11·4	37·7	44·3	11,190	Stripping lower bench
Do.	6·1	9·3	35·6	49·0	11,390	Stripping
Cadomin, Mile 22 (Mountain Park Branch) ...	0·9	6·9	29·1	63·1	14,488	Usual
Blackstone Coal, Limited, Mile 53¾ ...	5·11	15·03	34·76	45·10	10,440	,,

Description of Mining Operations.—Contrary to the usual interpretation of the term "mining" as applied to the coal-industry, the greater part of the coal in this district is steam-shovelled—that is, it is actually obtained from the surface outcrops much in the same way as railway-ballast or gravel. A few coal-mines operated in the orthodox fashion certainly exist in this neighbourhood, but it is quite impossible for them to compete commercially with the steam-shovel operators.

As a general rule, the overburden is almost negligible, as it consists of soft glacial clays or gravels, or more rarely of a few feet of friable weathered sandstone. In certain cases the coal is in perfect condition for the application of the steam-shovel, as small faults and dislocations have slickensided and fractured the coal to such an extent that it can be easily recovered. In few instances only is blasting resorted to, and this usually to remove a high face which is out of reach of the operating tool.

Oliphant-Munson Mine (*Mile* 47).—This is probably one of the most remarkable coal-mines in the world. By reference to Figs. 1 and 5 to 8 it will be seen that the main excavations have been along the outcrop, and, despite continued operations in this area for a considerable time, there are still many millions of tons of good-grade coal in sight.

The forces of nature have been particularly well disposed in this mine, as the coal occurs on the surface. Two complementary seams (originally forming the flanks of a small anticlinal fold) have been faulted together at the apex, thus producing a workable deposit 182 feet in thickness. Two steam-shovels (Figs. 6 and 8) are continually at work, and it is possible to load over 1,000 tons of coal in the trucks every 24 hours.

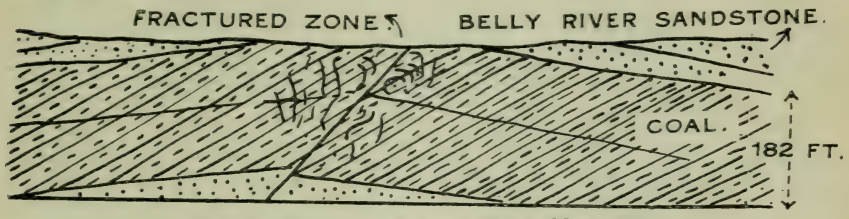


Fig. 1.—Oliphant-Munson Mine (Mile 47).

In order to remove the coal recovered by the shovel, two small trains (or " dinkies "), each drawing eight or ten trucks, are employed, and these quickly transport the coal to the electrically-driven screen. Here the material is separated by means of the inclined screen into its various sizes, and all the slack or small coal is loaded separately for use in smelting operations. An interesting contrivance known as a " box-car loader " is used for the purpose of expediting the despatch of the coal-train. This automatically loads and packs the coal into the commodious " box-cars " used on the Canadian railways, and so obviates the employment of a gang of men for this purpose.

The workings extend fully a quarter-of-a-mile into the coal, and on either side cliffs of solid black coal occur up to 30 feet in height.

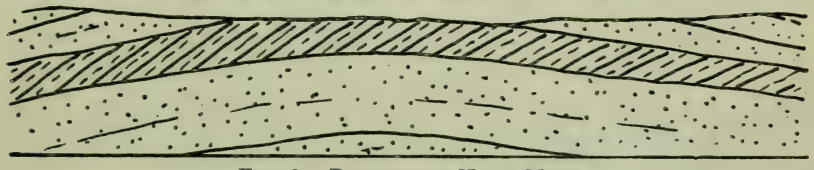


Fig. 2.—Blackstone No. 1 Mine.

A close examination of the coal-face reveals the fact that the material is slickensided, faulted, and folded to a minor extent, especially near the fault-contact of the two opposing seams of coal. This, however, is by no means detrimental to the quality of the coal. On the other hand, the slight dislocations are an advantage to the operator, as the coal is in a more accessible condition for the steam-shovel.

In local areas the coal contains a small amount of " bone," which consists for the most part of calcareous material interveined with iron pyrites.

Lenses of coarse sandstone (containing plant-remains) are common in certain zones, as well as concretionary masses of argillaceous sand.

Blackstone No. 1 Mine (Fig. 2).—At this mine the coal occurs at the crest of a comparatively flat anticline. There is no solid overburden, the only material on the surface of the outcrop being loose gravel and earth of glacial origin. After stripping in the usual way, the coal is immediately loaded into the trucks.

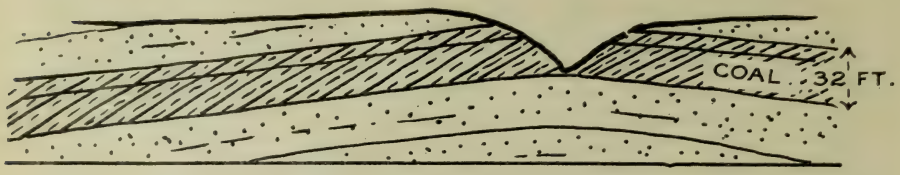


Fig. 3.—Blackstone No. 6 Mine.

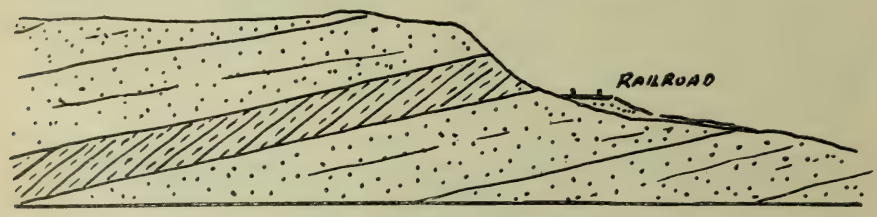


Fig. 4.—Foothills Colliery.

Fig. 5.—General View of Oliphant-Munson Colliery (note Cliffs of Coal on each Side).

Fig. 6.—Steam-shovel at Work.

Blackstone No. 6 Mine (Figs. 3, 9, and 10).—The geological conditions at Blackstone No. 6 Mine are very similar to those at No. 1, the seam occurring on the crest of a fold. In this case, however, a sandstone layer about 10 feet in thickness forms the overburden. To the east of the exposure a deep "coulee" (or short tributary to the Little Pembina River) has excavated a valley, thereby exposing the coal-seam. Operations were started from this point, and so the face was

Fig. 7.—Loosening the Top Face of the Coal.

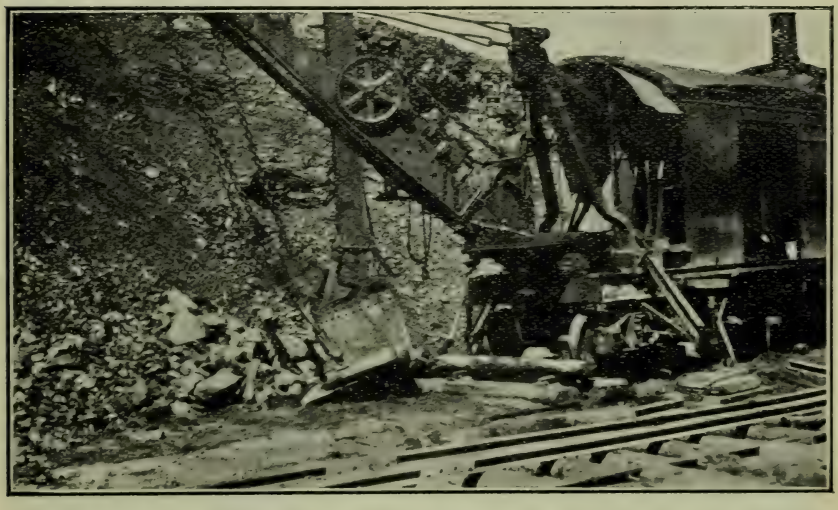


Fig. 8.—Type of Shovel Used.

worked back to its present dimensions. Towards the west of the exposure lenses of sandstone interfinger the coal, but apart from this the deposits form no difficulty for the steam-shovel.

Foothills Colliery (Figs. 4 and 11).—By reference to Fig. 4 it will be seen that this mine is one operated by the usual methods. The coal-seam dips to the west at a low angle, and the face is thereby exposed

along the railway-cutting. A shaft follows the seam, and the coal is removed by horse traction to the trucks in the railway-siding.

Lt.-Col. HARRY RHODES (Rotherham): Could the author of the paper give us any information with regard to the output per man obtained from these open-cast mines? If the paper had been on open-cast mining

FIG. 9.—BLACKSTONE NO. 6 MINE, SHOWING SANDSTONE OVERBURDEN (SHOVEL RESTING ON TOP OF COAL-SEAM).

FIG. 10.—BLACKSTONE NO 6 MINE, SHOWING PRINCIPAL SEAM WITH OVERBURDEN.

in the United States, the question would have had a great deal more interest for me in that respect. I have never been able to find out whether, in ascertaining the output per man in the United States, the amount of coal mined in that country by open-cast working is taken into account. I have been informed that in some of the open-cast workings

in the United States the output per man, instead of being 600 tons a year, is 600 tons a day! If 2 or 3 per cent. of the whole output of the country is got by mines of that description, it is easier to account for the increased output per man, as compared with this country.

Mr. George Sheppard (Edmonton, Alta.) wrote: Given favourable conditions, it is a comparatively easy matter for a steam-shovel crew of eight men to load 1,000 tons in 24 hours. But local factors in the operations decrease production to an appreciable extent.

Before any coal is loaded into the freight-cars, a certain amount of time must necessarily be taken up by stripping. In addition to this, the time spent in switching the cars and in screening the coal must also be taken into account.

I am of the opinion that the apparent increase of output per man in the United States, as compared with England, is due to the fact that the production of open-cast workings is averaged in the annual statistics.

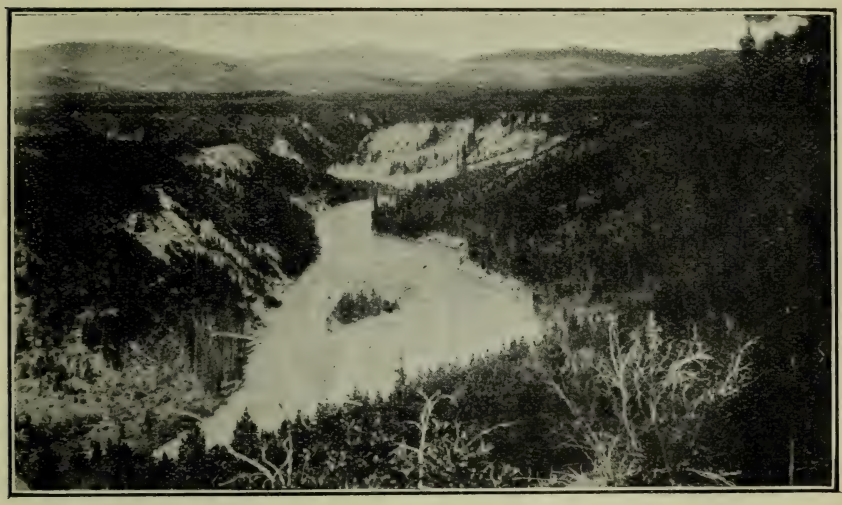


Fig. 11.—General View of Foothills Country (the Brazeau River Valley).

According to Colonel Rhodes' information, 600 tons per day per man is certainly high, but it is not beyond bounds of reasonable possibility if the local conditions for loading are ideal.

DISCUSSION OF MR. J. P. REES'S PAPER ON "OBSERVATIONS OF TEMPERATURE AND MOISTURE IN DEEP COAL-MINES."*

Mr. Eric Davies (Morro Velho, Brazil) wrote: With reference to the curves of moisture-content illustrating the results obtained in the various underground tests dealt with in this most valuable paper, all of these (with the exception, perhaps, of that in Fig. 9, Plate III.) exhibit in a more or less marked degree the main features which one has learnt to expect in diagrams of this nature—that is, a gradual rise throughout the intake, followed by a much more rapid one as the ventilating current traverses the working-face. Some of these curves, however,

* *Trans. Inst. M. E.*, 1920-1921, vol. lxi., page 102.

possess a minor feature which is rather difficult to understand and as regards which it would be interesting to have some explanation from the author. The feature referred to is the distinct fall in absolute moisture-content of the ingoing air immediately after leaving the downcast shaft, which is shown in Fig. 2 (points 3 and 4), Fig. 4 (points 2, 3, and 4), Fig. 6 (points 3 and 4), and Fig. 9 (points 2 and 3); in this last figure the absolute moisture-content is also shown to be less at the bottom of the downcast shaft than at the surface. This last result would appear to be a quite impossible one, in view of the fact that the air was throughout below the saturation-point and warming up; in the other cases a possible solution certainly does exist, namely, that there was a second downcast shaft at each mine which was in a considerably dryer condition than that at which the pit-bottom observation was made; but that this is so is nowhere mentioned by the author, and would seem, therefore, to be an unlikely one. There remain then, in my opinion, three possible reasons for these anomalous results, as under :—

(1) That the respective readings were taken in each case with a time-interval between them long enough for the initial moisture-content of the air entering the mine to vary considerably (if this were the case the observations would have little comparative value, and the diagrams would be worthless to a large extent).

(2) That the dry- and wet-bulb temperatures and barometric pressures at these points, which are necessary for calculating the absolute moisture-contents, were incorrectly read.

(3) That the method of calculating the absolute moisture-contents from these readings was an incorrect one.

Of these, (1) and (2) need not be considered further, in view of the ability and experience in this class of work of those responsible for carrying out the observations. However, with all due deference to the author, I do think it possible that (3) may be the true explanation, the more especially since he himself states that these moisture-contents were not actually calculated, but were obtained by applying a correction of some sort to figures given in tables.

The calculation of the absolute moisture-content of atmospheres in which the barometric pressure is above or below the normal sea-level value is not a subject usually met with in text-books, and, in view of the growing interest which must necessarily be taken in these matters as mines get deeper and hotter all over the world, it seems to me that a description of the method which I have been using at Morro Velho for the last seven or eight years may not be without value to other experimenters in this field. Although in my case it has always given consistent results over a large number of underground tests similar to those referred to in the present paper, I am naturally quite open to conviction if the author or anyone else should be able to point out any flaw or inaccuracy in it.

The method in question is based on an equation given in Lucke's *Engineering Thermodynamics*, where it is attributed to Prof. Ferrel as the result of extensive experiments conducted by the United States Weather Bureau.

Let T denote the dry-bulb temperature in degrees Fahrenheit.
" W " " wet-bulb " " " "
" A " " atmospheric pressure in pounds per square inch (*i.e.*, the corrected barometer reading in inches of mercury divided by 2·035).

Let S denote the pressure of saturated steam corresponding to temperature W in pounds per square inch.

,, V denote the partial pressure in pounds per square inch of the water-vapour in the atmosphere under consideration.

$$\text{Then } V = S - 0{\cdot}000367\ A(T-W)\left\{1-\left(\frac{W-32}{1{,}571}\right)\right\} \qquad (1)$$

Knowing T, W, and A from observation, and finding S from a pressure-temperature curve for saturated steam (as given in miniature on the accompanying diagram (Fig. 1), V may be calculated from equation (1). Hence t, the dew-point temperature, in degrees Fahrenheit, may be found from the pressure-temperature curve, being that temperature at which the pressure is V. From the lower curve on Fig. 1, in which the density of saturated steam is plotted against temperature, the density of the water-vapour at dew-point temperature in pounds per cubic foot is then found, where d, the vapour-density at the actual temperature T, may be calculated from the equation—

$$d = \delta \times \frac{t + 459{\cdot}6}{T + 459\ 6} \qquad (2)$$

Then, since A is the sum of the partial pressures exerted by the dry air and the water-vapour, if P denote the dry-air pressure in pounds per square inch—

$$P = A - V \qquad (3)$$

Hence, if D denote the density of the dry air—

$$D = \frac{P \times 144}{(T + 459{\cdot}6) \times 53{\cdot}34} \qquad (4)$$

Hence, finally, the absolute moisture-content in grains of water-vapour per pound of dry air is given by the expression $(d \times 7{,}000)/D$; should the unit preferred be grains per cubic foot at 32° Fahr. and 14·70 pounds per square inch absolute (the author's), then, since 1 pound of dry air under these conditions occupies 12·39 cubic feet, the expression for moisture-content becomes $(d \times 7{,}000)/(D \times 12{\cdot}39)$.

As an example of this method, Table I is given, in which the absolute moisture-contents for points 3 and 4 in Fig. 2, Plate II. (Pendleton Colliery), and points 3 and 4 in Fig. 4 (Shelton Deep Pit) are worked out. The dry- and wet-bulb temperatures (T and W) were obtained by scaling off the author's charts, while the barometric pressures (A) were estimated from the depths given on the charts, assuming normal sea-level pressure to prevail at the surface; hence these figures may very possibly not be absolutely correct. It is noteworthy, however, that in each case the method described above gives a higher absolute moisture-content at the point further from the downcast shaft (as would naturally be expected), whereas the author's charts, as already stated, show a contrary result.

The general impression given by the author in Sections II. and III. of the paper is that as the air descends a mine its density remains approximately constant, the increase resulting from increase of pressure being balanced by the decrease resulting from increase of temperature. This is certainly true for many British coal-mines, where the air-temperature rise per unit of depth is comparatively rapid, but it is by no means true for other parts of the world, such, for example, as the Witwatersrand or Morro Velho, where the air-temperature rises at a much slower rate, and where the air-density at the mine-bottom is

consequently very considerably higher than at the surface; in the case of Morro Velho this increase amounts at times to as much as 15 per cent.

Table I.

	Fig. 2, Plate II., Vol. LXI.		Fig. 4, Plate II., Vol. LXI.	
	Point 3.	Point 4.	Point 3.	Point 4.
T degrees Fahrenheit	67·9	73·6	66·1	68·8
W ,, ,,	61·5	64·6	59·2	60·8
A pounds per square inch	15·52	15·97	16·10	16·33
S ,, ,, ,,	0·270	0·300	0·248	0·264
$T - W$ degrees Fahrenheit	6·4	9·0	6·9	8·0
$1 - \left\{ (W-32)/1571 \right\}$	0·9812	0·9792	0·9827	0·9817
$0{\cdot}000367\ A\ (T-W)\{1-(W-32)/1571\}$ pounds per square inch	0·036	0·052	0·040	0·047
V [from equation (1)] ,, ,,	0·234	0·248	0·208	0·217
t degrees Fahrenheit	57·5	59·2	54·2	55·4
δ pounds per cubic foot	0·000763	0·000808	0·000685	0·000711
d [from equation (2)] ,, ,,	0·000748	0·000786	0·000669	0·000693
P [,, (3)] ,, square inch	15·29	15·72	15·89	16·11
D [,, (4)] ,, cubic foot	0·0782	0·0796	0·0816	0·0823
Grains of vapour per pound of dry air ...	66·9	69 1	57·4	58·9
,, ,, cubic foot at N.T.P.	5·40	5·58	4·63	4·76
,, ,, ,, ,, ,, ,, (scaled from author's charts)	5·56	5·26	4·60	4·40

As regards the Storrow whirling hygrometer illustrated in the paper (Fig. 12), when I was at Bentley Colliery in 1919, Mr. J. Ivon Graham very kindly showed me some of these instruments, and on my subsequent return to Morro Velho I had a similar one made up. This I took into the mine and tested against one of the brass-cased portable-type Mason hygrometers (as described in Mr. Henry Davis's Paper, "The Application of the Hygrometer in Coal-mines," *Trans. Inst. M. E.*, 1907-1908, Vol. XXXV., page 285, and illustrated in Fig. 2 of that paper), which I had been using for some years. I must say that I felt rather anxious about this test, fearing lest the comparison might show all my previous wet-bulb readings to have been too high. The result, however, was reassuring, since the two instruments tallied exactly where the velocity of the passing (horizontal) air-current was 300 feet per minute and over, which was the case at all the points where I had been taking regular underground readings; only in still air or in air moving vertically, as at shaft-landings, did the wet-bulb thermometer of the stationary instrument give a markedly higher reading than that of the whirling instrument. I have, therefore, continued to use the

portable stationary-type instrument for underground work, where its greater ease of transport, and the time that it saves (due to the fact that it can be left suspended in the air-current until it gives a steady reading while other work, such as measuring the ventilation, rock-temperatures, etc., is being proceeded with), make it, in my opinion, more advantageous than the whirling type.

Finally, and with reference to the remark in the introductory portion of the paper as to rock taking up heat from the air in warm weather, the chart on Fig. 2 may be of interest. It relates to observations made at Morro Velho, and shows for the three years from July, 1915, to July, 1918, inclusive (1) the average monthly air-temperatures (dry-bulb) at

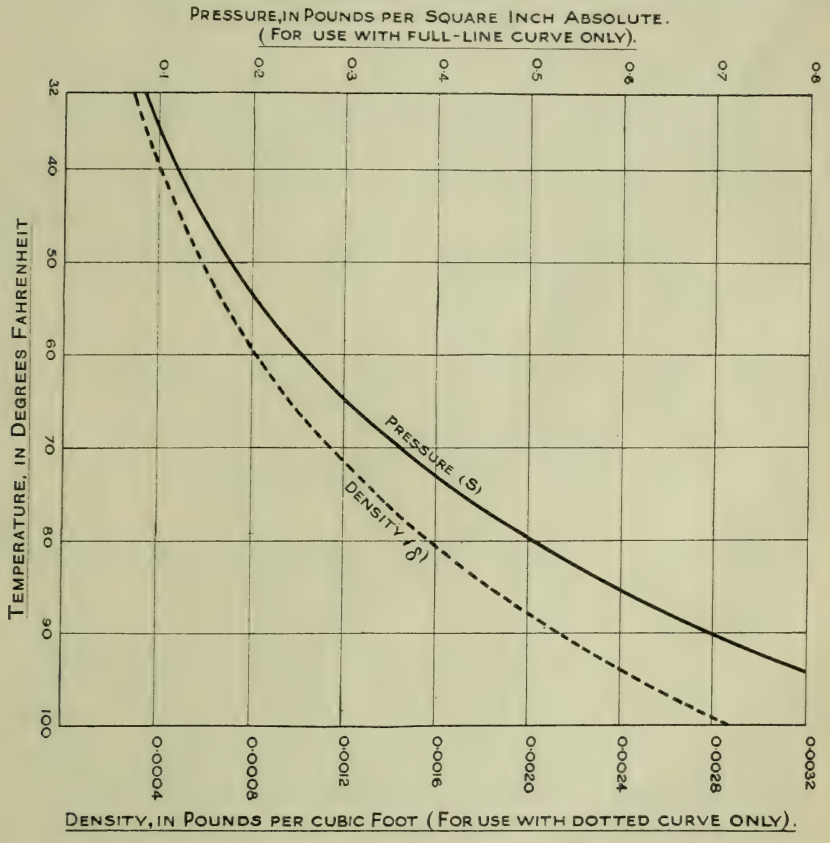


Fig. 1.—Pressure and Density Curves for Saturated Steam between 32° and 100° Fahr.

the top of the downcast shaft (Curve A), and (2) the monthly rock-temperature readings at three points passed by the downcast air-current (*a*) at the Adit Level, 324 feet below the surface (Curve B), (*b*) at Level No. 8, 2,264 feet below the surface (Curve C), and (*c*) at Level No. 12, 3,424 feet below the surface (Curve D). All these rock-temperature readings were taken at the bottom of holes in the rock 10 feet deep, the ends of the holes being closed by means of an iron door about $\frac{1}{2}$ inch thick, with a pad (made from old canvas-belting) forming an airtight joint between the door and the rock-face around the hole, which is cemented smooth for this purpose. These curves show clearly the give and take of heat between the rock and the ventilating

current in accordance with the seasonal changes of temperature of the outside air. Another interesting point which they bring out is the time-lag effect; the peaks and valleys of Curve B seem to occur on the average about 40 days behind those of Curve A, while Curve C similarly appears to lag about 43 days (average) behind Curve B. Curves C and D, however, keep fairly well in step with each other.

Mr. J. P. Rees (Birmingham University) wrote: Mr Davies has remarked on an interesting feature shown by several of the charts, of which no explanation is given in my paper. This feature is the fall in

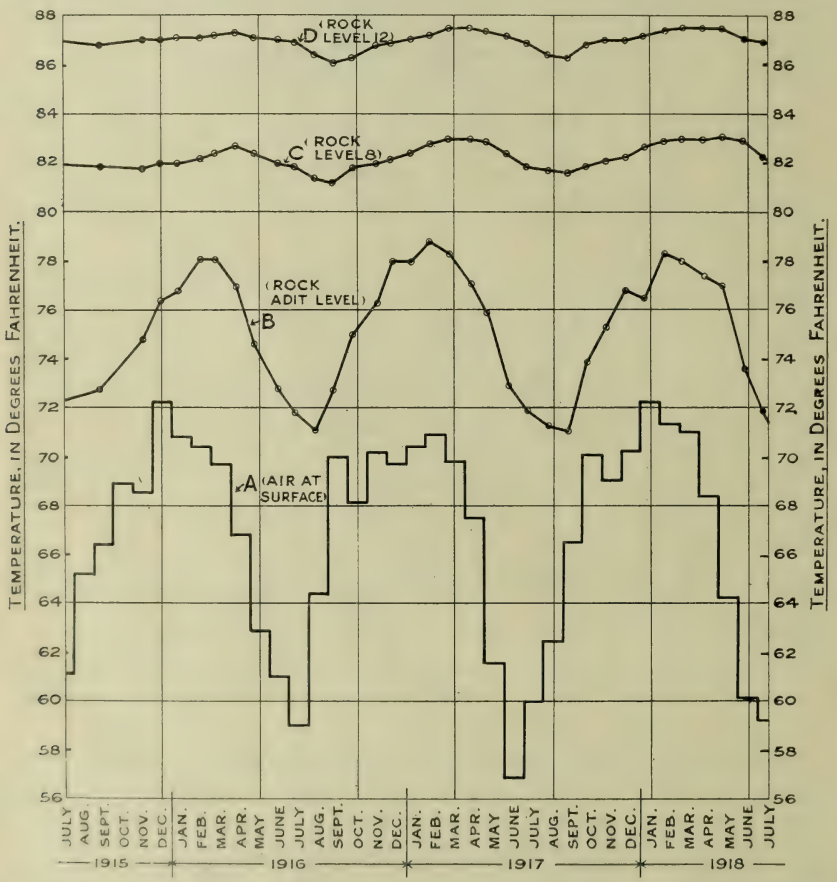


Fig. 2.—Surface Air- and Underground Rock-temperatures at the Morro Velho Mine, Brazil.

absolute moisture-content of the ingoing air immediately after leaving the bottom of the downcast shaft. The explanation of this is that the walls and dust in the intake airways act, within limits, as an automatic regulator of the moisture-content of the air. When the absolute moisture-content rises, the walls adsorb moisture from the air and tend to keep it dry; and, on the other hand, when the moisture-content of the air falls, the walls give off moisture to the air, tending to keep it wet. Generally, during the night the moisture-content of the air falls and the walls become drier; during the day the moisture-content of the ingoing air rises and the walls adsorb moisture from it.

The observations on which the charts are based were made generally during the morning, and consequently the effect is seen of the air being dried as it passes along the intake airways. In shallow pits the drying of the air is very much more marked, especially during the hot weather of summer. In such pits the air as it travels towards the workings is cooled below the dew-point, and condensation takes place—that is, during hot summer weather. The walls of the shaft and roads will then become clammy and damp with this moisture condensed from the air. In deeper pits the heating effect of compression is sufficient to prevent this from happening; nevertheless, on a hot summer's day at Bentley Colliery the moisture-content of the ingoing air is reduced below that of the air at the surface by partial condensation and adsorption. This effect is shown in Fig. 9 (Plate III., Vol. LXI.).

Mr. Davies suggests that an explanation of this reduction in moisture-content is that the method of calculating the results is incorrect. In order to test this point, he has worked out the absolute moisture-content from figures that he has scaled off the charts. It is unfortunate that it is impossible to scale off figures from the charts with any real accuracy, chiefly owing to the small scale to which the charts had to be printed. The figures from which the points were plotted are as follows:—

		Fig. 2, Plate II., Vol. LXI.		Fig. 4, Plate II., Vol. LXI.	
		Point 3.	Point 4.	Point 3.	Point 4.
T	degrees Fahrenheit	67·7	73·7	65·9	69·3
W	,, ,,	62·4	64·7	59·5	60·5
A	pounds per square inch	15·4	15·8	15·9	16·1
Grains of vapour per cubic foot at N.T.P.		5·80	5·67	4·78	4·59
do.	do. (from tables)	5·50	5·36	4·70	4·52

Mr. Davies has done a service to those interested in this subject by bringing together the formulæ on which the calculation of the absolute moisture-content is based. The tables I have used in my calculations (Psychrometric Tables of the U.S. Department of Agriculture, Weather Bureau) are based on Prof. Ferrel's equation, as given by him. Slight discrepancies may be introduced in the different methods used of calculating the vapour-density and in correcting for pressure differences. But, as will be seen from the results I have worked out from the equations which Mr. Davies gives, the agreement by the two methods is reasonably close. It is impossible to expect an agreement consistently within 2 or 3 per cent., owing to some of the fundamental data never having been accurately determined. However, the use of the tables avoids calculations that would, when a large number of results were being worked out, become rather laborious.

My remark in Section II. of the paper, that the correction for pressure is "almost negligible," is misleading. The correction referred to is one that can be made when obtaining the relative humidity. The weight of a cubic foot of aqueous vapour (or the moisture-content) has in all cases been corrected both for pressure and temperature, and this latter correction is often quite appreciable. In Section III. of the paper the

effect of the change of temperature and pressure on the wet bulb is referred to, and in this case I found the effect was negligible.

Mr. Davies' experience with a stationary hygrometer agrees with the experience of those who have been working under the Committee, although a speed of rather more than 300 feet per minute is considered safer. One objection to a brass-cased instrument compared with a wooden case is that the metal requires a longer time to adjust itself to a change in temperature, and is liable to affect the thermometers until it has done so. Three readings can be obtained with the whirling hygrometer in about five minutes.

The curves of rock-temperatures taken by Mr. Davies at the Morro Velho Mine are extremely interesting and valuable. Data of an analogous nature will shortly be forthcoming in a future Report of the Committee.

Mr. Eric Davies wrote: I have read with great interest Mr. Rees's explanation of the principal point I raised in my contribution to the discussion on his paper; it is one that had certainly never occurred to me, as the phenomenon of adsorption of moisture by the walls and dust of the airways does not appear to take place in the Morro Velho Mine, or, if so, not to any measurable extent.

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EXPLANATIONS.

The — at the beginning of a line denotes the repetition of a word or words followed by a comma in the preceding entry; and in the case of Names, it includes both the Christian Name and the Surname; or, in the case of the name of any Firm, Association, or Institution, the full name of such Firm, etc.

Discussions are printed in *italics*.

The following contractions are used :—

M. C.—The Midland Counties Institution of Engineers.

M. G.—The Manchester Geological and Mining Society.

M. I.—The Midland Institute of Mining, Civil, and Mechanical Engineers.

N. E.—The North of England Institute of Mining and Mechanical Engineers.

N. S.—The North Staffordshire Institute of Mining Engineers.

S. I.—The Mining Institute of Scotland.

S. S.—The South Staffordshire and Warwickshire Institute of Mining Engineers.

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The Institution of Mining Engineers.

FOUNDED JULY 1ST, 1889; INCORPORATED BY ROYAL CHARTER FEBRUARY 9TH, 1915.

NOTICE OF ANNUAL GENERAL MEETING.

THE THIRTY-SECOND ANNUAL GENERAL MEETING of The Institution of Mining Engineers will be held in the Town Hall, Stoke-on-Trent, on Wednesday, September 14th, 1921, at 11 o'clock a.m.

The members will be welcomed to the district by the Mayor of Stoke-on-Trent (Alderman Sampson-Walker).

The agenda for the Annual General Meeting, and the programme of the excursion and other arrangements made by the Council of the North Staffordshire Institute of Mining Engineers, is attached hereto.

Ladies are cordially invited to join several of the excursions and to be present at the dinner on September 14th, and the reception on September 15th.

The attention of members is directed to the necessity of completing the attached reply-circular and returning it to Mr. A. J. B. Atkinson (40, High Street, Newcastle, Staffordshire) NOT LATER THAN SEPTEMBER 6th.

C. McDERMID,
Secretary.

CLEVELAND HOUSE,
225, CITY ROAD, E.C. 1.
August 25th, 1921.

AGENDA-PROGRAMME.

HEADQUARTERS.—During the Meeting the Headquarters of the members will be at the North Stafford Hotel, Stoke-on-Trent. The management have quoted from 11s. per head for bedroom, breakfast, attendance, and lights; and, for similar accommodation, the Grand Hotel, Hanley, have quoted 9s. Other good hotels are: Hanley, The Saracen's Head; Newcastle-under-Lyme, The Borough Arms.

As hotel accommodation is very limited, it is essential for members to make immediate application for rooms.

Members' letters may be addressed during the meeting week: c/o THE NORTH STAFFORD HOTEL, Stoke-on-Trent, and the envelope should bear on the left-hand corner the words "Mining Engineers" for identification purposes.

Wednesday, September 14th, 1921.

ANNUAL GENERAL MEETING.

11.0 a.m.—Annual General Meeting at the Town Hall, Stoke-on-Trent.

The Mayor of Stoke-on-Trent (Alderman Sampson-Walker) will attend and welcome the members.

The PRESIDENT (Col. W. C. Blackett, C.B.E.) will open the Annual General Meeting.

The Thirty-second Annual Report of the Council will be read.

The names of the Officers for the year 1921-1922 will be announced.

The Institution Auditors will be elected.

The Newly-elected President will take the Chair and deliver an ADDRESS.

The following papers will be read, or taken as read :—

(1) "The Adsorption or Solubility of Methane and other Gases in Coal, Charcoal, and other Substances," by J. Ivon Graham, M.A., M.Sc., Chief Chemist, Doncaster Coal-owners' Laboratory.

(2) "Suggestions for the Standardization of Geological Sections of Strata proved in Boreholes, Shafts, etc.," by Harry Roscoe, O.B.E.

(3) "Coal-mining by Steam Shovel in Alberta, Canada," by George Sheppard.

The following papers, which have already appeared in the Transactions, will be open for discussion :—

(*a*) "Third Report of the Committee on 'The Control of Atmospheric Conditions in Hot and Deep Mines' : Observations of Temperature and Moisture in Deep Coal-mines," by J. P. Rees, A.R.S.M., vol. lxi., page 101.

(*b*) "Characteristics of Outbursts of Gas in Mines," by Prof. Henry Briggs, D.Sc., Ph.D., A.R.S.M., vol. lxi., page 119.

1.0 p.m.—Adjournment for Luncheon.

Luncheon may be had at the North Stafford Hotel at 4s. each (to be paid at the time). There are also several restaurants in the vicinity.

2.30 p.m.—The Annual General Meeting will be resumed.

5.0 p.m.—The Annual General Meeting will be closed.

Advance Copies of Papers.

Members desirous of taking part in the discussion of papers to be read at this Meeting may obtain from the Secretary an advance copy of each of the papers in which they are interested. Written remarks thereon are invited from those who may be unable to be present. It is desirable that, where possible, all remarks should be typewritten, and a copy sent in advance to the Secretary, The Institution of Mining Engineers, Cleveland House, 225, City Road, London, E.C. 1.

EXCURSION NO. 1.

China Works of Messrs. Cauldon, Limited.

For Ladies Only.

2.45 p.m.—Ladies taking part in this excursion will assemble at the North Stafford Hotel, Stoke-on-Trent, and will be conducted to the China works of Messrs. Cauldon, Limited.

3.0 p.m.—Arrive at the works, and make an inspection of the Showrooms.

DINNER.

6.45 p.m. (for 7.0 p.m. prompt).—Dinner at the Town Hall, Stoke-on-Trent.

Tickets, exclusive of wine, 15s. each (to be paid in advance).

Ladies are cordially invited to attend the Dinner.

Orders and Decorations will be worn.

Members wishing to be seated next to their friends should notify Mr. Atkinson by returning the counterfoils of their dinner tickets, duly filled in and signed, not later than September 6th.

As the arrangements in connexion with the Dinner must be settled definitely at least a week beforehand, and as it is proposed to issue a plan showing the seats allotted to each member, it is absolutely necessary that applications for tickets for the Dinner should be sent in not later than the above-mentioned date, after which date no tickets will be issued.

It will not be possible to make any alteration in the seating arrangements after that date.

Thursday, September 15th, 1921.

EXCURSION NO. 2.

WHITFIELD COLLIERY OF THE CHATTERLEY-WHITFIELD COLLIERIES, LIMITED, NORTON-IN-THE-MOORS, STOKE-ON-TRENT; AND THE ENGINEERING WORKS OF MESSRS. KERR, STUART, & COMPANY, LIMITED, STOKE-ON-TRENT.

9.45 a.m.—Members will leave the North Stafford Hotel, Stoke-on-Trent, for Whitfield Colliery by motor-conveyances. Fare, 5s. each (to be paid in advance).

10.15 a.m.—Arrive at Whitfield Colliery and inspect the surface arrangements.

1.0 p.m.—Luncheon by kind invitation of the Chatterley-Whitfield Collieries, Limited.

2.30 p.m.—Leave Whitfield Colliery by motor-conveyances for the works of Messrs. Kerr, Stuart, & Company, Limited, Stoke-on-Trent.

3.15 p.m.—Arrive at California Works, Stoke-on-Trent, and inspect the works and plant, etc.

4.30 p.m.—Leave California Works by motor-conveyances for Stoke-on-Trent.

4.45 p.m.—Arrive at the North Stafford Hotel.

or

EXCURSION NO. 3.

THE COLLIERIES AND WORKS OF THE SHELTON IRON, STEEL, & COAL COMPANY, LIMITED, ETRURIA, STOKE-ON-TRENT.

10.15 a.m.—Members will leave the North Stafford Hotel, Stoke-on-Trent, by motor-conveyances for Deep Pit, Hanley. Fare, 2s. each (to be paid in advance).

10.30 a.m.—Arrive at Deep Pit and inspect the surface arrangements.

12.30 p.m.—Leave Deep Pit by motor-conveyances.

12.45 p.m.—Luncheon by kind invitation of the Shelton Iron, Steel, & Coal Company, Limited.

2.30 p.m.—Arrive at Etruria works and inspect the iron and steel works and coking plant.

4.15 p.m.—Leave works.

Trains leave Etruria Station for Stoke at 4.43, 4.53, and 5.15 p.m.

N.B.—Members attending Excursion No. 2 cannot take part in Excursion No. 3, and *vice versa.*

EXCURSION NO. 4.

CHINA WORKS OF MESSRS. JOSIAH WEDGWOOD & SONS, LIMITED, ETRURIA, STOKE-ON-TRENT.

FOR LADIES ONLY.

Ladies taking part in this excursion will assemble at the North Stafford Hotel, Stoke-on-Trent, and will be conducted to Messrs. Wedgwood's works.

10.35 a.m.—Leave Stoke-on-Trent Railway Station for Etruria, and walk ($\frac{1}{4}$ mile), to Messrs. Wedgwood's well-known manufactory, where they will be met and conducted over the showrooms and works.

Trains leave Etruria for Stoke-on-Trent at 12.34 and 12.54 p.m.

EXCURSION NO. 5.

Silk Mills of Messrs. William Watson, Limited, Leek.
For Ladies Only.

The President and Council of the North Staffordshire Institute of Mining Engineers cordially invite all ladies attending the meeting to join this excursion.

Ladies taking part in this excursion will assemble at the North Stafford Hotel, Stoke-on-Trent, and will be conducted to Messrs. Watson's mills.

2.15 p.m.—Leave North Stafford Hotel, Stoke-on-Trent, by motor-conveyances.

3.0 p.m.—Arrive at mills, and make an inspection.

4.0 p.m.—Leave mills and proceed to the Red Lion Hotel for tea.

4.45 p.m.—Leave Leek for Stoke-on-Trent.

5.30 p.m.—Arrive at the North Stafford Hotel.

RECEPTION.

8.0 p.m.—Reception at the Town Hall, Stoke-on-Trent, by the kind invitation of the North Staffordshire Colliery Owners' Association. Ladies are cordially invited.

Music (refreshments will be provided).

Friday, September 16th, 1921.

EXCURSION NO. 6.

A tour round the North Staffordshire Coalfield will be made by motor-conveyances. Mr. J. T. Stobbs, F.G.S., will lead the tour and point out the leading geological and other features of the district.

A map of the North Staffordshire Coalfield will be issued to those taking part in the excursion.

Luncheon will be taken at Moreton Old Hall, near Congleton. The Hall is one of the finest examples of old half-timbered houses in the country.

The party will leave the North Stafford Hotel at 10 a.m. and return there before 4 p.m., in time to allow members to take trains home the same evening.

Motor-conveyance fare, 7s. each (to be paid in advance).

Luncheon, including entrance-fee to Moreton Old Hall, 5s. each (to be paid in advance).

Members wishing to do so may leave the party after luncheon at Congleton Station in time to take the 2.55 p.m. train to Manchester.

Issue of Transactions.

Part 5 of Volume LX. and Parts 3 and 4 of Volume LXI. were issued to members on July 18th, August 3rd, and August 25th, 1921.

Notice of the Publication of each Part is contained in the first subsequent circular issued to members, and in case of non-receipt immediate intimation should be given to the Secretary. Duplicate copies of any Parts can only be supplied to members on payment of 5s. each, or in some cases 10s., plus postage, provided that such parts are in stock.

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mining eng.

The Institution of Mining Engineers.

FOUNDED JULY 1ST, 1889; INCORPORATED BY ROYAL CHARTER FEBRUARY 9TH, 1915.

Telegraphic Address:
"INSTIMINI, PHONE, LONDON."
Telephone: VICTORIA 2149.

ALBANY BUILDINGS,
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WESTMINSTER, LONDON, S.W. 1.

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JUN 7 1921

May 23rd, 1921.

DEAR SIR,

THE SEVENTY-FIFTH GENERAL MEETING of the Members of THE INSTITUTION OF MINING ENGINEERS will be held in the Rooms of the Geological Society, Burlington House, Piccadilly, London, W.1, on THURSDAY, JUNE 9TH, at 11 a.m.

Owing to the present state of the coal-mining industry, and the difficulty of securing the attendance of Members and Guests, it has been decided not to hold the usual Dinner this year.

A Visit to the National Physical Laboratory, Teddington, will take place on Friday, June 10th.

On the invitation of the President and Council of the North Staffordshire Institute of Mining Engineers, the Thirty-Second Annual General Meeting of the Members will be held at Stoke-on-Trent on Wednesday, Thursday, and Friday, September 14th, 15th, and 16th, 1921.

I am, dear Sir,

Your obedient Servant,

PERCY STRZELECKI,

Secretary.

Advance Copies of Papers.

Members desirous of taking part in the discussion of papers to be read at this Meeting may obtain an advance copy of each of the papers in which they are particularly interested from the Secretary, who will be pleased to receive written remarks thereon from those who may be unable to be present. It is desirable that, where possible, all remarks should be typewritten, and a copy sent in advance to the Secretary.

N.B.—Copies of the papers will be posted as soon as they are available, and the omission of any particular paper should be taken as an indication that it has not been received from the printers, but will be forwarded later.

SEVENTY-FIFTH GENERAL MEETING,

LONDON, JUNE 9TH AND 10TH, 1921.

COL. W. C. BLACKETT, C.B.E., T.D., D.L., LL.D., M.Sc, PRESIDENT.

AGENDA-PROGRAMME.

HOTEL ACCOMMODATION.—The Waldorf Hotel, Aldwych, W.C. 2, has quoted an inclusive rate of 15s. 6d. per day for a single room, with light, attendance, use of bathroom, and table d'hôte breakfast. Other good hotels are: The Regent Palace, Piccadilly Circus, W. 1; The Grosvenor, Victoria, S.W. 1; and The Grand Hotel and Hotel Victoria, Northumberland Avenue, W.C. 2.

Members should make application for their rooms forthwith, otherwise they may be unable to obtain accommodation in London.

The Rooms of the Geological Society, Burlington House, Piccadilly, London, W. 1, will be open during the meeting from 10 a.m. to 5 p.m. for the registration of addresses, issue of programmes and papers, etc.

Members' letters may be addressed during the meeting: c/o THE GEOLOGICAL SOCIETY, Burlington House, Piccadilly, London, W. 1, and the envelopes should bear on the left-hand corner the words "Mining Engineers" for identification purposes.

Thursday, June 9th, 1921.

11.0 a.m.—General Meeting in the Rooms of the Geological Society, Burlington House, Piccadilly, London, W. 1.

The PRESIDENT will open the meeting.

The following papers will be read, or taken as read:—

(1) "Third Report of the Committee on 'The Control of Atmospheric Conditions in Hot and Deep Mines': Observations of Temperature and Moisture in Deep Coal-mines," by J. P. Rees, A.R.S.M.

(2) "Characteristics of Outbursts of Gas in Mines," by Prof. Henry Briggs, D.Sc., A.R.S.M.

(3) "The Use and Distribution of Shale-dust in Mines," by Mr. H. C. Harrison.

The following papers, which have already appeared in the Transactions, will be discussed:—

(*a*) "The Better Utilization of Coking Slack," by A. E. Beet, B.Met., and A. E. Findley, B.Sc., A.I.C., etc., vol. lx., page 213.

(*b*) "The Normal Occurrence of Carbon Monoxide in Coal-mines," by J. Ivon Graham, M.A., M.Sc., Chief Chemist, Doncaster Coal-owners' Laboratory, vol. lx., page 222.

(*c*) "An Improved Method of Determining the Relative Directions of Two Reference-lines or Bases for Mining Surveys," by T. Lindsay Galloway, M.A., F.R.S.E., vol. lx., page 235.

(*d*) "Froth Flotation as Applied to the Washing of Industrial Coal," by Ernest Bury, Walter Broadbridge, and Alfred Hutchinson, vol. lx., page 243.

1.0 p.m.—An adjournment will be made for Luncheon.

2.30 p.m.—The General Meeting will be resumed.

5.0 p.m.—The General Meeting will be closed.

Friday, June 10th, 1921.

VISIT TO THE NATIONAL PHYSICAL LABORATORY, TEDDINGTON.

9.46 a.m.—Leave Waterloo Station (L. & S.-W. Railway) by electric train for Teddington.

Return Fares: First Class, 4s. 4½d.; Third Class, 2s. 8d.

10.21 a.m.—Arrive Teddington and walk (10 minutes) to the National Physical Laboratory (Bushy House), where the Members will be received by Sir Joseph Petavel, K.B.E., F.R.S., Director of the Laboratory. The following departments will be inspected:—Engineering; Electricity; Heat and Thermometry; Metrology (length measurements, surveying tapes, etc.); Aeronautics; and the Ship Tank.

1.30 p.m.—Luncheon will be provided in the New Canteen at a charge of 2s. each (to be paid at the time).

The Members visited the Laboratory in 1903, at which date the work was carried on mainly in Bushy House, and in a small Engineering Laboratory. The Laboratory has steadily and rapidly developed since then, and now comprises twelve large buildings for research and test-work in all branches of Physics, and in Mechanical and Electrical Engineering, Metallurgy, Aeronautics, and Ship Design. The work is organized in the following Departments:—

(1) Physics, including Heat and Thermometry, Optics, and Radiology.
(2) Electricity, including Electrotechnics and Wireless Research.
(3) Metrology (measures of length, time, and mass) and Gauge-testing.
(4) Engineering.
(5) Metallurgy.
(6) Aeronautics.
(7) The William Froude National Tank.

The chief functions of the Laboratory are the maintenance of fundamental standards of measurement, length standards, electrical standards, etc., the carrying-out of tests on all classes of instruments and on materials, and research. The research-work is largely in connexion with technical problems. Special investigations are also carried out for Research Associations and private firms, for which a charge is made.

Electric trains leave Teddington for Wimbledon, Clapham Junction, Vauxhall, and Waterloo.

VISIT TO BATTLEFIELDS OF VERDUN, ETC.

The Council of the British Section of the Société des Ingénieurs Civils de France invites the Members of this Institution to take part in the Summer Meeting, to be held in France between June 18th and 24th next, when it is intended to visit the eastern part of France, including the Battlefields of Verdun and the Factories of the Lorraine area. Ladies are cordially invited to take part in the Meeting.

Each Member or Lady joining the party will be asked to pay the sum of Frs. 725. This amount will cover (*a*) the general expenses of the Meeting from Paris to Paris; (*b*) first-class train and motor-car fares (with an allowance for luggage of 45 pounds per head); (*c*) hotels at Longwy and Metz, with meals (exclusive of wines); (*d*) all expenses connected with visits to Works, Mines, Battlefields, etc.; and (*e*) all gratuities. It does not include the fares from England to Paris nor hotel accommodation in Paris.

During the Meeting (from Thursday the 16th until Saturday the 25th June) an Information Bureau will be open at the offices of The Société des Ingénieurs Civils de France in Paris (19, rue Blanche), and a room will be placed at the disposal of the members of the party.

Applications to take part in the meeting should be sent in *not later than Friday, May 27th*, stating whether accompanied by a lady or not.

Further details may be obtained on application to Mr. Percy Strzelecki, 39, Victoria Street, Westminster, London, S.W. 1.

IMPORTANT NOTICES TO MEMBERS.

Issue of Transactions.

Parts 5 and 6 of Volume LIX., Parts 1, 2, 3, and 4 of Volume LX., and Parts 1 and 2 of Volume LXI. were issued to the Members on October 5th and November 27th, 1920; and on January 8th, February 2nd, March 8th, March 31st, May 6th, and May 23rd, 1921.

Notice of the Publication of each Part is contained in the first subsequent circular issued to the Members, and in case of non-receipt immediate intimation should be given to the Secretary. Duplicate copies of any Parts can only be supplied to Members at the published price, plus postage, but cannot even then be had if the Parts have been stitched together into volumes.

Sale of Transactions.

Copies of Vols. I. to LIX. (lacking Vols. XXXVIII. and XXXIX., which are now out of print) of the *Transactions* of The Institution of Mining Engineers will be supplied to Members only, to complete their sets, in paper covers, for £38 0s.; and single volumes can be supplied at the following rates:—Vols. I. and XLI. at £2 each; Vols. II. and III. at £1 5s. each; Vols. IV. to XXIII., XXVI. to XXIX., XXXII., XXXIII., XXXV., and XLII. to LIX., at 10s. each; Vols. XXIV., XXV., XXXI., XXXIV., XXXVI., and XXXVII., at £1 each; Vols. XXX. and XL., at £1 10s. each; duplicate volumes for any year (with the above exceptions), can only be supplied at £3 each year; postage in addition in each case. To Non-Members, Vols. I., II., III., and XLI., at £3 12s. each, and Vols. IV. to XXXVII., XL., and XLII. to LIX. at £1 16s. each; postage in addition. Bound copies will be supplied if desired.

Letting of Council Chamber.

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OF

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GENERAL MEETINGS, 1922:—
(Annual), September.
London, June.

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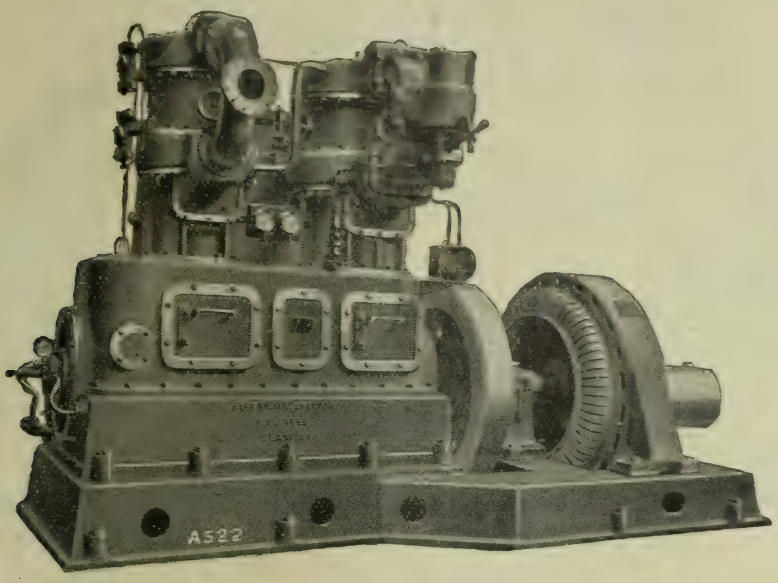

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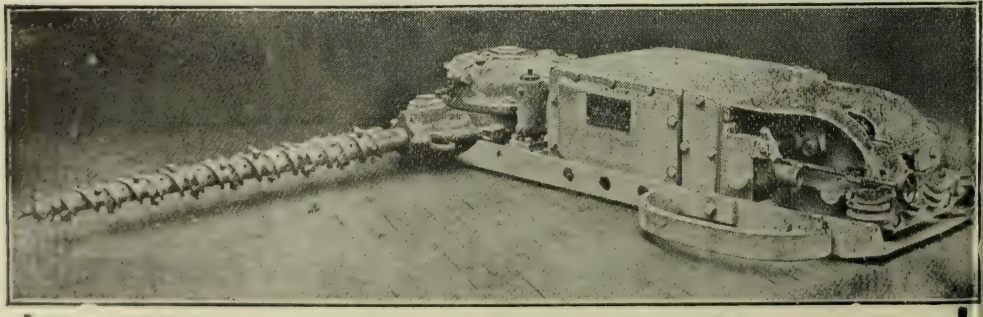

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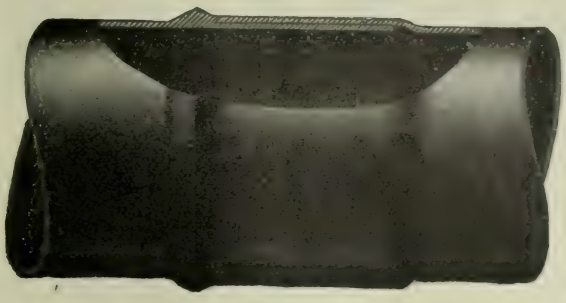

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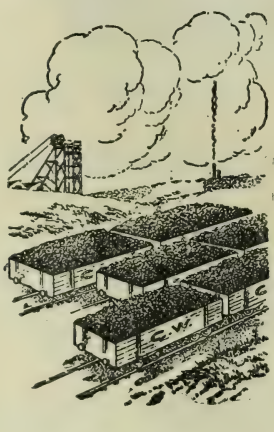

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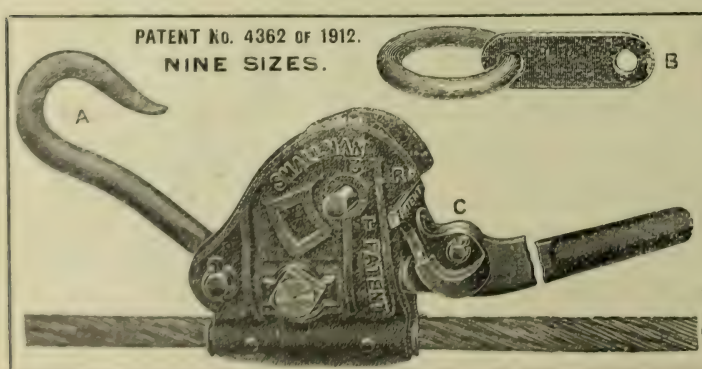

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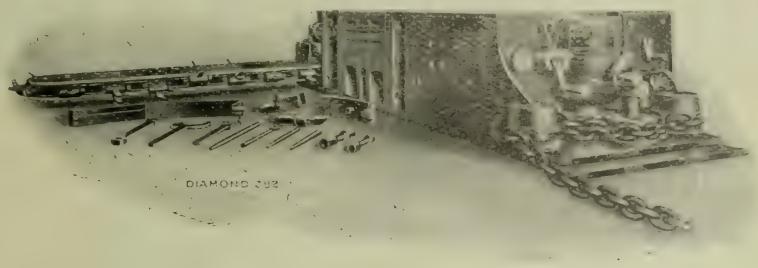

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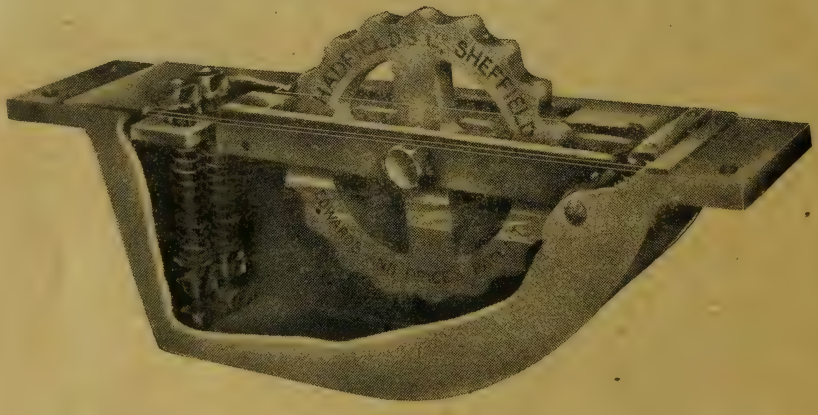

Illustration of Right-hand Greaser with portion of trough and lid removed.

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